AUTHENTICATED
U.S. GOVERNMENT
INFORMATION
GPO

THE NATIONAL NANOTECHNOLOGY INITIATIVE: REVIEW AND OUTLOOK

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

MAY 18, 2005

Serial No. 109–15

Printed for the use of the Committee on Science

Available via the World Wide Web: http://www.house.gov/science

U.S. GOVERNMENT PRINTING OFFICE

21–195PS WASHINGTON : 2005

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2250 Mail: Stop SSOP, Washington, DC 20402–0001

COMMITTEE ON SCIENCE

HON. SHERWOOD L. BOEHLERT, New York, *Chairman*

RALPH M. HALL, Texas
LAMAR S. SMITH, Texas
CURT WELDON, Pennsylvania
DANA ROHRABACHER, California
KEN CALVERT, California
ROSCOE G. BARTLETT, Maryland
VERNON J. EHLERS, Michigan
GIL GUTKNECHT, Minnesota
FRANK D. LUCAS, Oklahoma
JUDY BIGGERT, Illinois
WAYNE T. GILCHREST, Maryland
W. TODD AKIN, Missouri
TIMOTHY V. JOHNSON, Illinois
J. RANDY FORBES, Virginia
JO BONNER, Alabama
TOM FEENEY, Florida
BOB INGLIS, South Carolina
DAVE G. REICHERT, Washington
MICHAEL E. SODREL, Indiana
JOHN J.H. "JOE" SCHWARZ, Michigan
MICHAEL T. MCCAUL, Texas
VACANCY
VACANCY

BART GORDON, Tennessee
JERRY F. COSTELLO, Illinois
EDDIE BERNICE JOHNSON, Texas
LYNN C. WOOLSEY, California
DARLENE HOOLEY, Oregon
MARK UDALL, Colorado
DAVID WU, Oregon
MICHAEL M. HONDA, California
BRAD MILLER, North Carolina
LINCOLN DAVIS, Tennessee
RUSS CARNAHAN, Missouri
DANIEL LIPINSKI, Illinois
SHEILA JACKSON LEE, Texas
BRAD SHERMAN, California
BRIAN BAIRD, Washington
JIM MATHESON, Utah
JIM COSTA, California
AL GREEN, Texas
CHARLIE MELANCON, Louisiana
VACANCY

SUBCOMMITTEE ON RESEARCH

BOB INGLIS, South Carolina, *Chairman*

LAMAR S. SMITH, Texas
CURT WELDON, Pennsylvania
DANA ROHRABACHER, California
GIL GUTKNECHT, Minnesota
FRANK D. LUCAS, Oklahoma
W. TODD AKIN, Missouri
TIMOTHY V. JOHNSON, Illinois
DAVE G. REICHERT, Washington
MICHAEL E. SODREL, Indiana
MICHAEL T. MCCAUL, Texas
VACANCY
SHERWOOD L. BOEHLERT, New York

DARLENE HOOLEY, Oregon
RUSS CARNAHAN, Missouri
DANIEL LIPINSKI, Illinois
BRIAN BAIRD, Washington
CHARLIE MELANCON, Louisiana
EDDIE BERNICE JOHNSON, Texas
BRAD MILLER, North Carolina
VACANCY
VACANCY
VACANCY
BART GORDON, Tennessee

DAN BYERS *Subcommittee Staff Director*
JIM WILSON *Democratic Professional Staff Member*
ELIZABETH GROSSMAN, KARA HAAS *Professional Staff Members*
JAMES HAGUE *Staff Assistant*

CONTENTS

May 18, 2005

	Page
Witness List	2
Hearing Charter	3

Opening Statements

Statement by Representative Bob Inglis, Chairman, Subcommittee on Research, Committee on Science, U.S. House of Representatives	11
Written Statement	12
Statement by Representative Darlene Hooley, Ranking Minority Member, Subcommittee on Research, Committee on Science, U.S. House of Representatives	12
Written Statement	13
Prepared Statement by Representative Eddie Bernice Johnson, Member, Subcommittee on Research, Committee on Science, U.S. House of Representatives	15
Prepared Statement by Representative Michael M. Honda, Member, Subcommittee on Research, Committee on Science, U.S. House of Representatives	15
Prepared Statement by Representative Russ Carnahan, Member, Subcommittee on Research, Committee on Science, U.S. House of Representatives	16

Witnesses:

Mr. Scott C. Donnelly, Senior Vice President for Global Research; Chief Technology Officer, General Electric	
Oral Statement	16
Written Statement	19
Biography	20
Financial Disclosure	21
Dr. John M. Kennedy, Director, Center for Advanced Engineering Fibers and Films, Clemson University	
Oral Statement	22
Written Statement	23
Financial Disclosure	30
Dr. John M. Cassady, Vice President for Research, Oregon State University	
Oral Statement	31
Written Statement	33
Biography	38
Financial Disclosure	39
Mr. Michael Fancher, Director of Economic Outreach, Associate Professor of Nanoeconomics, Albany Nanotech	
Oral Statement	39
Written Statement	42
Biography	48
Financial Disclosure	49
Discussion	50

Appendix 1: Answers to Post-Hearing Questions

Page

Dr. John M. Cassady, Vice President for Research, Oregon State University 66

Appendix 2: Additional Material for the Record

Statement of Bob Gregg, Executive Vice President, FEI Company 68

The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, President's Council of Advisors on Science and Technology, May 2005 70

THE NATIONAL NANOTECHNOLOGY INITIATIVE: REVIEW AND OUTLOOK

WEDNESDAY, MAY 18, 2005

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bob Inglis [Chairman of the Subcommittee] presiding.

SUBCOMMITTEE ON RESEARCH
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The National Nanotechnology Initiative: Review and Outlook

Wednesday, May 18, 2005
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building (WEBCAST)

Witness List

Mr. Scott Donnelly
Senior Vice President
General Electric

Dr. John Kennedy
Director, Center for Advanced Engineering Fibers and Films
Clemson University

Dr. John Cassady
Vice President for Research
Oregon State University

Mr. Michael Fancher
Director of Economic Outreach
Albany NanoTech

Section 210 of the Congressional Accountability Act of 1995 applies the rights and protections covered under the Americans with Disabilities Act of 1990 to the United States Congress. Accordingly, the Committee on Science strives to accommodate/meet the needs of those requiring special assistance. If you need special accommodation, please contact the Committee on Science in advance of the scheduled event (3 days requested) at (202) 225-6371 or FAX (202) 225-0891.
Should you need Committee materials in alternative formats, please contact the Committee as noted above.

HEARING CHARTER

SUBCOMMITTEE ON RESEARCH
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The National Nanotechnology Initiative: Review and Outlook

WEDNESDAY, MAY 18, 2005
10:00 A.M.—12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Wednesday, May 18, 2005, the Research Subcommittee of the Committee on Science of the House of Representatives will hold a hearing to review the activities of the National Nanotechnology Initiative (NNI).

2. Witnesses

Mr. Scott Donnelly is the Senior Vice President for Global Research for the General Electric Company.

Dr. John Kennedy is Director of the Center for Advanced Engineering Fibers and Films (CAEFF) at Clemson University. CAEFF is a National Science Foundation-supported Engineering Research Center.

Dr. John Cassady is Vice President for Research at Oregon State University (OSU). OSU plays a leading role in the Oregon Nanoscience and Microtechnologies Institute.

Mr. Michael Fancher is Director of Economic Outreach at Albany NanoTech. He is also Associate Professor of Nanoeconomics at the State University of New York at Albany, College of Nanoscale Science and Engineering.

3. Overarching Questions

- Which fields of science and engineering present the greatest opportunities for breakthroughs in nanotechnology, and which industries are most likely to be altered by those breakthroughs in both the near-term and the longer-term?
- What are the primary barriers to commercialization of nanotechnology, and how can these barriers be overcome or removed? What is the Federal Government's role in facilitating the commercialization of nanotechnology innovations, and how can the current federal nanotechnology program be strengthened in this area?
- What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

4. Brief Overview

- In December 2003, the President signed the *21st Century National Nanotechnology Research and Development Act* (P.L. 108–153), which originated in the Science Committee. This Act provided a statutory framework for the interagency National Nanotechnology Initiative (NNI), authorized appropriations for nanotechnology research and development (R&D) activities through fiscal year 2008 (FY08), and enhanced the coordination and oversight of the program. Funding for the NNI has grown from $464 million in fiscal year 2001 (FY01) to $1.1 billion in FY05, and 11 agencies currently have nanotechnology R&D programs.
- In addition to federal investments, State governments and the private sector have become increasingly involved in supporting nanotechnology. In 2004, the private sector in the U.S. invested roughly $2 billion in nanotechnology re-

search, while states invested roughly $400 million. The state investment is primarily spent on infrastructure and research at public universities, while the private funding focuses on applied research and development activities at small and large companies, and funding for start-up nanotechnology ventures.

- The *21st Century National Nanotechnology Research and Development Act* required that a National Nanotechnology Advisory Panel (NNAP) biennially report to Congress on trends and developments in nanotechnology science and engineering and on recommendations for improving the NNI. The first such report will be released on May 18. Its recommendations include strengthening Federal-industry and Federal-State cooperation on nanotechnology research, infrastructure, and technology transfer, and broadening federal efforts in nanotechnology education and workforce preparation.

5. Background

Overview of Nanotechnology

The National Academy of Sciences describes nanotechnology as the "ability to manipulate and characterize matter at the level of single atoms and small groups of atoms." An Academy report describes how "small numbers of atoms or molecules. . .often have properties (such as strength, electrical resistivity, electrical conductivity, and optical absorption) that are significantly different from the properties of the same matter at either the single-molecule scale or the bulk scale." Scientists and engineers anticipate that nanotechnology will lead to "materials and systems with dramatic new properties relevant to virtually every sector of the economy, such as medicine, telecommunications, and computers, and to areas of national interest such as homeland security." [1]

Nanotechnology is an enabling technology and, as such, its commercialization does not depend specifically on the creation of new products and new markets. Gains can come from incorporating nanotechnology into existing products, resulting in new and improved versions of these products. Examples could include faster computers, lighter materials for aircraft, less invasive ways to treat cancer, and more efficient ways to store and transport electricity. Some less-revolutionary nanotechnology-enabled products are already on the market, including stain-resistant wrinkle-free pants, ultraviolet-light blocking sun screens, and scratch-free coatings for eyeglasses and windows.

In October 2004, a private research firm released its most recent evaluation of the potential impact of nanotechnology. The analysis found that, in 2004, $13 billion worth of products in the global marketplace incorporated nanotechnology. The report projected that, by 2014, this figure will rise to $2.6 trillion—15 percent of manufacturing output in that year. The report also predicts that in 2014, ten million manufacturing jobs worldwide—11 percent of total manufacturing jobs—will involve manufacturing these nanotechnology-enabled products.[2]

National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a multi-agency research and development (R&D) program. The goals of the NNI, which was initiated in 2000, are to maintain a world-class research and development program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and the infrastructure and tools to support the advancement of nanotechnology; and to support responsible development of nanotechnology. Currently, 11 federal agencies have ongoing programs in nanotechnology R&D; funding for those activities is shown in Table 1. Additionally, 11 other agencies, such as the Food and Drug Administration, the U.S. Patent and Trademark Office, and the Department of Transportation, participate in the coordination and planning work associated with the NNI.

---

[1] *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative,* National Research Council/National Academy of Sciences, 2002.

[2] Lux Research, "Sizing Nanotechnology's Value Chain," October 2004.

Table 1. Funding for the National Nanotechnology Initiative (Dollars in Millions)

	FY04 Actual	FY05 Estimated	FY06 Proposed
National Science Foundation	256	338	344
Department of Defense	291	257	230
Department of Energy	202	210	207
National Institutes of Health	106	142	144
National Institute of Standards and Technology	77	75	75
National Aeronautics and Space Administration	47	45	32
Environmental Protection Agency	5	5	5
National Institute for Occupational Safety & Health	0	3	3
U.S. Department of Agriculture	2	3	11
Department of Justice	2	2	2
Department of Homeland Security	1	1	1
Total	**989**	**1081**	**1054**

Source: The National Nanotechnology Initiative—Supplement to the Presidents FY06 Budget Request

In 2003, the Science Committee wrote and held hearings on the *21st Century National Nanotechnology Research and Development Act,* which was signed into law on December 3, 2003. The Act authorizes $3.7 billion over four years (FY05 to FY08) for five agencies (the National Science Foundation, the Department of Energy, the National Institute of Standards and Technology, the National Aeronautics and Space Administration, and the Environmental Protection Agency). The Act also: adds oversight mechanisms—an interagency committee, annual reports to congress, an advisory committee, and external reviews—to provide for planning, management, and coordination of the program; encourages partnerships between academia and industry; encourages expanded nanotechnology research and education and training programs; and emphasizes the importance of research into societal concerns related to nanotechnology to understand the impact of new products on health and the environment.

National Nanotechnology Advisory Panel Report

The *21st Century National Nanotechnology Research and Development Act* required the establishment or designation of a National Nanotechnology Advisory Panel (NNAP) to assess and provide advice on the NNI. In July 2004, the President designated the existing President's Council of Advisors on Science and Technology to serve as the NNAP. The NNAP's responsibilities include providing input to the administration on trends and developments in nanotechnology and on the conduct and management of the NNI.

The NNAP is required to report to Congress on its activities every two years, and its first report will be formally released on May 18, 2005. (Its content is described below.) The report assesses the U.S. position in nanotechnology relative to the rest of the world, evaluates the quality of current NNI programs and program management, and recommends ways the NNI could be improved.

Benchmarking

The NNAP report finds that U.S. leads the rest of the world in nanotechnology as measured by metrics such as level of spending (both public and private), publications in high-impact journals, and patents. The report also finds, however, that other countries are increasing their efforts and investments in nanotechnology and are closing the gap with the U.S. Some countries cannot afford to invest as broadly as the U.S., which has supported nanotechnology efforts relevant to a wide range of industries, but these other countries—particularly in Asia—have instead chosen to concentrate their investments in particular areas to make strides in a specific sector. For example, Korea and Taiwan are investing heavily in nanoelectronics while Singapore and China are focusing on nanobiotechnology and nanomaterials, respectively.

NNI Management

The NNAP report finds that the NNI is a well managed program. The report notes that the balance of funding among different areas of nanotechnology is appro-

priate and emphasizes the importance of investment in a diverse array of fields rather than a narrow focus on a just a few "Grand Challenges." In particular, the NNAP lauds the NNI for advancing the foundational knowledge about control of matter at the nanoscale; creating an interdisciplinary nanotechnology research community and an infrastructure of over 35 nanotechnology research centers, networks, and user facilities; investing in research related to the environment, health, safety, and other societal concerns; establishing nanotechnology education programs; and supporting public outreach.

Recommendations

The NNAP recommends continued strong investment in basic research and notes the importance of recent federal investment in research centers, equipment, and facilities at universities and national laboratories throughout the country (see Appendix A). Such facilities allow both university researchers and small companies to have access to equipment too expensive or unwieldy to be contained in an individual laboratory.

The NNAP also emphasizes the importance of State and industry contributions to the U.S. nanotechnology efforts and recommends that the NNI expand federal-state and federal-industry interactions through workshops and other methods.

The NNAP also recommends that the Federal Government actively use existing government programs such as the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs to enhance technology transfer in nanotechnology. All grant-giving agencies are required by law to have SBIR and STTR programs, and some of them specifically target solicitations toward nanotechnology. However, it is hard to get a clear, up-to-date picture of how much funding is actually provided for nanotechnology-related projects in these programs and on what the demand for SBIR/STTR funding in this area is. The NNAP also recommends that federal agencies be early adopters and purchasers of new nanotechnology-related products in cases where these technologies can help fulfill an agency's mission.

The NNAP also finds that the NNI is making good investments in environmental, health, and safety research, and recommends that the Federal Government continue efforts to coordinate this work with related efforts in industry and at non-profits and with activities conducted in other countries. The NNAP emphasizes the importance of communication with stakeholders and the public regarding research and findings in this area.

Finally, the NNAP emphasizes the importance of education and workforce preparation and recommends that the NNI coordinate with Departments of Education and Labor to improve access to materials and methods being developed for purposes of nanotechnology education and training.

Challenges Ahead

The NNAP notes that successful adoption of nanotechnology-enabled products will require coordination between federal, State, academic, and industrials efforts (including for efficient commercialization of products), training of a suitable high-technology workforce, and development of techniques for the responsible manufacture and use of these products.

Developing a federal strategy to facilitate technology transfer of nanotechnology innovations is a particularly complex challenge because of the wide range of industry sectors that stand to benefit from nanotechnology and the range of time scales at which each sector will realize these benefits. The NNAP report provides examples of various possible nanotechnology applications and when they are expected to reach the product stage (Table 2). The applications cover sectors from information technology and health care to security and energy, and some applications are on the market now, while others are more than 20 years in the future.

Table 2: Areas of Opportunity for Nanotechnology Applications

Time Scale	Nanotechnology Applications
Near-term (1-5 years)	- Nanocomposites with greatly improved strength-to-weight ratio, toughness, etc. - Nanomembranes and filters (including for water purification and desalination) - Improved catalysts with one or more orders of magnitude less precious metal - Sensitive, selective, reliable solid-state chemical and biological sensors - Point-of-care medical diagnostic devices - Long-lasting, rechargeable batteries
Mid-term (5-10 years)	- Targeted drug therapies - Enhanced medical imaging - High efficiency, cost effective solar cells - Improved fuel cells - Efficient technology for water to hydrogen conversion - Carbon sequestration
Long-term (20+ years)	- Drug delivery through cell walls - Molecular electronics - All-optical information processing - Neural prosthetics for treating paralysis, blindness, etc. - Conversion of energy from the environment (thermal or chemical)

Source: Report of the National Nanotechnology Advisory Panel (2005)

As the NNAP report notes, the states are playing an increasing role in nanotechnology. In 2004, state funding for nanotechnology-related projects was $400 million, or approximately 40 percent of the total federal investment. To date, State funding for nanotechnology has been focused on infrastructure—particularly the construction of new facilities—with some research support being provided in the form of matching funds to public universities that receive federal research dollars. In addition to receiving state support, universities and national laboratories also leverage federal investments through industry contributions of funds or in-kind donations of equipment and expertise. The report on a 2003 NNI workshop on regional, State, and local nanotechnology initiatives lists 18 specific examples of these non-federal initiatives.[3] (Witnesses at the hearing will describe the specific approaches being taken in New York, South Carolina, and Oregon.)

In recent years, the focus has been on the construction of nanotechnology facilities, but as these building projects financed by federal, State, and private funding are completed, the nanotechnology community must consider how best to capitalize on these new resources. Specifically, funding will have to be found for operating expenses, and policies that will attract public and private sector users to these facilities will be needed on topics such as collaboration, intellectual property, and usage fees.

The diversity of industry sectors will be a challenge for developing appropriate education and workforce training programs in nanotechnology. The predicted scale and breadth of research and manufacturing jobs related to nanotechnology will require not only specialized programs but also integration of nanotechnology-related information into general science, technology, engineering, and mathematics education.

Finally, successful integration of nanotechnology into products will require an understanding of the standards and regulations needed to govern responsible manufacturing and use of nanotechnology-enabled products. Currently, $82 million of the NNI R&D funding is spent on research related to the societal implications of nanotechnology. Of this amount, $38.5 million is specifically directed at environmental, health, and safety research, while the remainder is for the study of economic, workforce, educational, ethical, and legal implications. In addition to this funding, relevant work is also ongoing in other NNI focus areas. One example is the development of measurement techniques at the nanoscale which are necessary to set standards that can be used for quality control of nanotechnology products and to manage compliance with safety regulations. Another example is the study of the basic mechanisms of interaction between nanoscale materials and biological sys-

[3] *Regional, State, and Local Initiatives in Nanotechnology* is the report on a workshop convened on September 30–October 1, 2003 by the Nanoscale Science, Engineering and Technology (NSET) Subcommittee, the interagency group that coordinates NNI activities. The report is available online at *http://www.nano.gov/041805Initiatives.pdf.*

tems, which can provide critical information for health care applications as well as safe use practices.

6. Witness Questions

The witnesses were asked to address the following questions in their testimony:

Questions for Mr. Scott Donnelly:

- What fields of science and engineering present the greatest opportunities for breakthroughs in nanotechnology, and what industries are most likely to be impacted by those breakthroughs in both the near-term and the longer-term?
- What are the primary barriers to commercialization of nanotechnology, and how can these barriers be overcome or removed?
- To what extent has GE made use of university research and of facilities at universities and national laboratories? How important are these resources to GE's research program and how could they be more helpful?

Questions for Dr. John Kennedy:

- How does the Clemson Center for Advanced Engineering Fibers and Films (CAEFF) interact with the private sector? What are the greatest barriers to increased academic/industrial cooperation in nanotechnology?
- How does the State of South Carolina provide support to CAEFF for nanotechnology and other high-technology activities? How does this complement funding from the Federal Government and the private sector? What, if any, gaps remain?
- What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?
- How can Federal and State governments, industry, and academia best cooperate to facilitate advances in nanotechnology?

Questions for Dr. John Cassady:

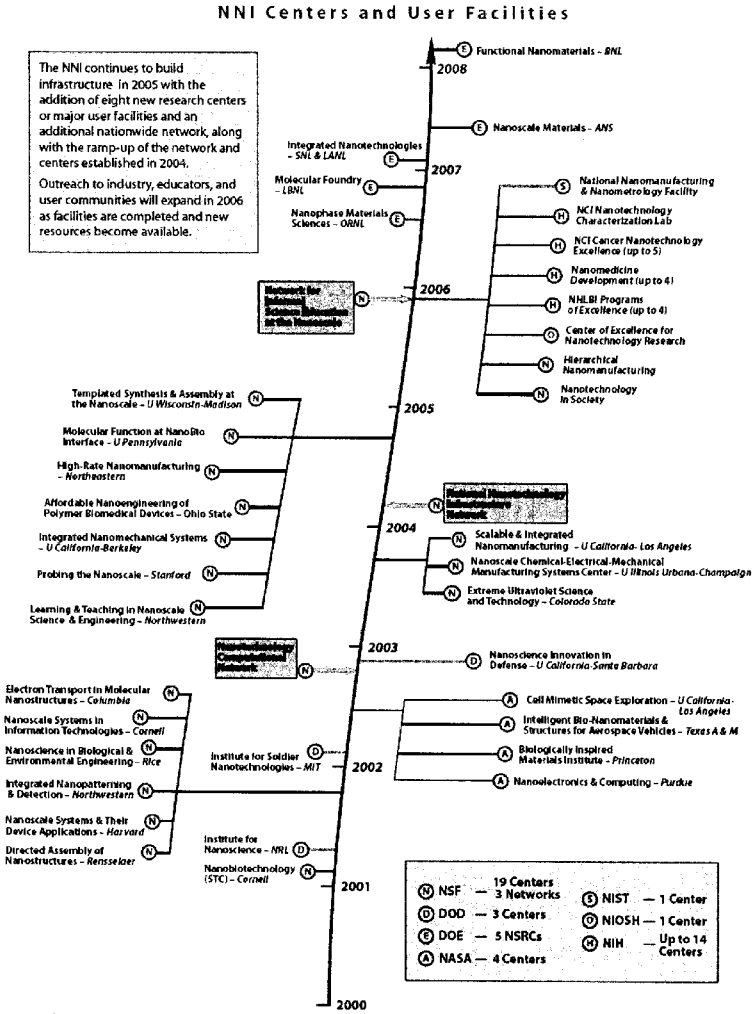
- How do Oregon State University (OSU) and the Oregon Nanoscience and Microtechnologies Institute (ONAMI) interface with the private sector? What are the greatest barriers to increased academic/industrial cooperation in nanotechnology?
- How does the State of Oregon provide support to OSU and ONAMI for nanotechnology and other high-technology activities? How does this complement funding from the Federal Government and the private sector? What, if any, gaps remain?
- What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?
- How can Federal and State governments, industry, and academia best cooperate to facilitate advances in nanotechnology?

Questions for Mr. Michael Fancher:

- How does Albany NanoTech interface with the private sector? What are the greatest barriers to increased academic/industrial cooperation in nanotechnology?
- How does the State of New York provide support to Albany NanoTech and the University of Albany College of Nanoscale Science and Engineering? How does this complement funding from the Federal Government and the private sector? What, if any, gaps remain?
- What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

- How can Federal and State governments, industry, and academia best cooperate to facilitate advances in nanotechnology?

Appendix A: National Nanotechnology Initiative Centers and User Facilities



Source: The National Nanotechnology Initiative—Supplement to the Presidents FY06 Budget Request

Chairman INGLIS. Good morning, everyone.

Thank you for joining us for this hearing on nanotechnology. It is good of you to come this morning to the Research Subcommittee on a topic of such small significance. I say that, of course, because what we are talking about here, science at the nanometer scale, starts at 1/75,000 of the width of a human hair. We are here to learn about nanotechnology, and I am excited to hear what our witnesses will have to say. So I will keep this opening statement small as well.

I also want to welcome Ranking Member Hooley. I was encouraged by her insightful questions at the last Research Subcommittee hearing, and I am looking forward to what she will contribute this morning. I am also seeing that she and I are dressed in the right colors for Oregon, is that right? And Clemson University, I would point out, Dr. Kennedy.

I am not a scientist by background, and I have got to confess that I didn't know enough about this subject until I had prepared for this hearing. I am not alone. A recent survey by MIT's technology review showed that more than half of all Americans have no familiarity with nanotechnology. That is a shame, because these technologies are changing the products we use and have the potential to revitalize our manufacturing base. We must be about educating our children in math and science if they will need to do these jobs. I know Ms. Hooley, being a former teacher, will have something to say about that as well.

This morning, the President's Council of Advisors on Science and Technology released a report on the state of and outlook for nanotechnology in the United States. On the whole, the report is very encouraging, noting that we lead the world by most metrics, including funding, patents, and scientific publications. But one of the things I found troubling is that other countries are catching up, and not just in funding. I hope we can talk today about the ways the United States can maintain its status as a world leader in these emerging technologies.

For those of us who are technologically challenged, like me, nanotechnology is the manipulation of matter at the molecular level to get results that just don't occur in larger lumps of atoms. It promises to impact virtually every field, with applications in fields from energy, to defense, to health care, to transportation. You can end up with things like gold-covered nanoshells to target and burn cancer away or light-weight, super strong materials structured at the smallest levels that could increase the efficiency of our airplanes and automobiles.

Our experts can talk more about nanotechnology's implications, but what we really want to know is how to get it into products that we will use in the future. Nanotechnology is one of the few technologies where basic research meets the marketplace in venture capital startups and R&D at large firms. The witnesses here today will bring the process to life and let us in government know how we are helping and how we may be hurting advances in this very promising area.

[The prepared statement of Chairman Inglis follows:]

PREPARED STATEMENT OF CHAIRMAN BOB INGLIS

Welcome. It's good of you to come to this hearing at the Research Subcommittee on a topic of such *small* significance. I say that, of course, because what we're talking about here—science at the nanometer scale—starts at a size 1/75,000th of the width of a human hair. We're here to learn about nanotechnology, and I'm excited to hear what our witnesses will have to say, so I'll keep this opening statement small as well.

I also want to welcome our Ranking Member, Ms. Hooley. I was encouraged by her insightful questions in our last Research Subcommittee hearing, and I'm looking forward to what she will contribute to this hearing.

I'm not a scientist by background, and I've got to confess that I didn't know enough about this subject until I had to prepare for this hearing. I'm not alone. A recent survey by MIT's Technology review showed that more than half of all Americans have no familiarity with nanotechnology. That's a shame, because these technologies are changing the products we use, and have the potential to revitalize our manufacturing base. We must be about educating our children in the math and science they will need to do these jobs. I know Ms. Hooley, being a former teacher, has a lot to say about this.

This morning, the President's Council of Advisors on Science and Technology released a report on the state of, and outlook for, nanotechnology in the U.S. On the whole, the report is very encouraging, noting that we lead the world by most metrics, including funding, patents, and scientific publications. But one of the things I find troubling is that other countries are catching up, and not just in funding. I hope we can talk today about ways the U.S. can maintain its status as a world leader in these emerging technologies.

For those of us who are technologically challenged—like me—nanotechnology is the manipulating of matter at the molecular level to get results that just don't occur in larger lumps of atoms. It promises to impact virtually every field—with applications in fields from energy to defense to health care to transportation. You can end up with things like gold-covered nanoshells to target and burn cancer away, or lightweight, super-strong materials structured at the smallest levels that could increase the efficiency of our airplanes and automobiles.

Our experts can talk more about nanotechnology's implications, but what we really want to know is how to get it into the products we will use in the future. Nanotechnology is one of the few technologies where basic research meets the marketplace in venture-capital startups and R&D at large firms. The witnesses here today will bring the process to life and let us in government know how we're helping and how we may be hurting advances in this very promising area.

Chairman INGLIS. With that, I would recognize Ms. Hooley for an opening statement.

Ms. HOOLEY. Thank you, Mr. Chair.

I am pleased to join you in welcoming our witnesses today to the oversight hearing on the National Nanotechnology Initiative, or the NNI. One of the signal accomplishments of the Science Committee in the last Congress was the development of the NNI authorization legislation, which was signed into law in December of 2003. Calling the technology revolutionary has become a cliché, but nanotechnology truly is revolutionary. A recent National Research Council report explains why this is so: "The ability to control and manipulate atoms to observe and stimulate collective phenomena to treat complex material systems and to span length scales from atoms to our everyday experience provides opportunities that were not even imagined a decade ago."

Nanotechnology will have an enormous consequence for the information industry, for manufacturing, and for medicine and health. Indeed, the scope of this technology is so broad as to leave virtually no product untouched. The NNI is a coordinated federal R&D effort that seeks to ensure the United States is at the forefront of research to develop nanotechnology and is positioned to benefit from its many potential applications.

The focus of this hearing is to review the initial assessment of the NNI by the President's Council of Advisors on Science and Technology. This assessment is mandated by statute and is required to cover both the content and the management of NNI.

Mr. Chairman, as you know, the Co-chair of PCAST was scheduled to appear today to present a report. However, the Administration suddenly and inexplicably found a constitutional objection to this appearance. This extraordinary constitutional interpretation would prevent a member of a statutorily mandated Advisory Committee from presenting a mandated report to Congress. I would hope the Science Committee will formally object to this action and will strenuously assert Congressional prerogatives for access to information about the implementation of this federal program, and we will talk about that when we get through.

One aspect of the NNI that the Advisory Committee report touches on and is of great interest to me is how the NNI helps facilitate commercialization of the technology. I believe that PCAST will have some recommendations for making the NNI more effective in this area. As the PCAST report points out, many states are investing in nanotechnology. And of course, the states play a leading role in economic development. Oregon is one of those states that has taken steps and made investments to help create new commercial enterprises founded on results flowing from nanoscience research.

I am delighted that one of our witnesses this morning is Dr. John Cassady, who is Vice President for Research at Oregon State University, and I did wear these colors in his honor today. Mr. Cassady is closely involved with the Oregon Nanoscience and Microtechnologies Institute, of what we call ONAMI, a collaboration between Oregon's three major research universities, federal research agencies, and the state's thriving high-tech sector. Dr. Cassady will be able to describe how Oregon is supporting nanotechnology development and how ONAMI, which emphasizes rapidly commercializing new technology, works in partnership with the private sector.

I hope to learn today how NNI could be more effective in helping transfer technology to the private sector and helping support the commercialization process. I will be interested in the experiences of our witnesses and in their recommendations.

Mr. Chair, I want to thank you for calling this hearing, and I want to thank our witnesses for appearing before the Subcommittee today, and I look forward to our discussion.

Thank you.

[The prepared statement of Ms. Hooley follows:]

PREPARED STATEMENT OF REPRESENTATIVE DARLENE HOOLEY

Mr. Chairman, I am pleased to join you in welcoming our witnesses today to this oversight hearing on the National Nanotechnology Initiative, or the NNI. One of the signal accomplishments of the Science Committee in the last Congress was the development of the NNI authorization legislation, which was signed into law in December 2003.

Calling a technology "revolutionary" has become a cliché. But nanotechnology truly is revolutionary. A recent National Research Council report explains why this is so:

> *"The ability to control and manipulate atoms, to observe and simulate collective phenomena, to treat complex materials systems, and to span length scales from*

atoms to our everyday experience, provides opportunities that were not even imagined a decade ago."

Nanotechnology will have enormous consequences for the information industry, for manufacturing, and for medicine and health. Indeed, the scope of this technology is so broad as to leave virtually no product untouched. The NNI is the coordinated federal R&D effort that seeks to ensure the U.S. is at the forefront of research to develop nanotechnology and is positioned to benefit from its many potential applications.

The focus of this hearing is to review the initial biennial assessment of the NNI by the President's Council of Advisors on Science and Technology. This assessment is mandated by statute and is required to cover both the content and the management of the NNI.

Mr. Chairman, as you know, the co-chair of PCAST was scheduled to appear today to present this report. However, the Administration suddenly and inexplicably found a constitutional objection to his appearance. This extraordinary constitutional interpretation would prevent a member of a statutorily mandated advisory committee from presenting a statutorily mandated report to Congress. I trust the Science Committee will formally object to this action and will strenuously assert congressional prerogatives for access to information about the implementation of federal programs.

One aspect of the NNI that the advisory committee report touches on and that is of great interest to me is how the NNI helps facilitate commercialization of the technology. I believe PCAST will have some recommendations for making the NNI more effective in this area. As the PCAST report points out, many States are investing in nanotechnology and, of course, the States play a leading role in economic development. Oregon is one of those States that has taken steps and made investments to help create new commercial enterprises founded on results flowing from nanoscience research.

I am delighted that one of our witnesses this morning is Dr. John M. Cassady, who is Vice President for Research at Oregon State University. Dr. Cassady is closely involved with the Oregon Nanoscience and Microtechnologies Institute (ONAMI), a collaboration between Oregon's three major research universities, federal research agencies, and the state's thriving high-tech sector.

Dr. Cassady will be able to describe how Oregon is supporting nanotechnology developments and how ONAMI, which emphasizes rapidly commercializing new technology, works in partnership with the private sector.

I hope to learn today how the NNI could be more effective in helping transfer technology to the private sector and in helping support the commercialization process. I will be interested in the experiences of our witnesses and in their recommendations.

Mr. Chairman, I want to thank you for calling this hearing and thank our witnesses for appearing before the Subcommittee today. I look forward to our discussion.

Chairman INGLIS. Thank you, Ms. Hooley.

I might take the prerogative of the Chair just to mention that we do agree with you that it is disappointing that we are not going to be able to hear from the President's advisor on this. We had hoped that he would be here to testify. The good news, however, is that the report is available at the back of the room and on the web. It would have been nice to have had the opportunity to ask questions and to see the full presentation of that, and yes, Ms. Hooley, the Science Committee is expressing our desires in that area and expressing the prerogatives of the House to have access to that process.

It was, however, a public process that developed the report and the report itself is public, so no secret deals here. It is just a matter that it would be better if he were here to make the presentation.

So other Members are invited to make opening statements available for publication in the record this morning.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman, for calling this very important hearing today. I welcome our distinguished witnesses.

The purpose of this hearing is to examine federal nanotechnology research and development and to explore the outlook for the future.

Nanotechnology is the act of manipulating matter at the atomic scale. Regardless of the diverse opinions on the rate at which nanotechnology will be implemented, people who make it a habit to keep up with technology agree on this: it is a technology in its infancy, and it holds the potential to change *everything*.

Research in nanoscience is literally exploding, both because of the intellectual allure of constructing matter and molecules one atom at a time, and because the new technical capabilities permit creation of materials and devices with significant societal impact. The rapid evolution of this new science and the opportunities for its application promise that nanotechnology will become one of the dominant technologies of the 21st century. Nanotechnology represents a central direction for the future of chemistry that is increasingly interdisciplinary and ecumenical in application.

Currently, manufacturing methods at the molecular level are very unsophisticated. Methods such as casting, grinding, milling and even lithography move atoms in cumbersome and unyielding manners. It has been compared to trying to make things out of LEGO blocks with boxing gloves on your hands. Yes, you can push the LEGO blocks into great heaps and pile them up, but you can't really snap them together the way they should be attached.

In the future, nanotechnology will let us take off the boxing gloves. We'll be able to snap together the fundamental building blocks of nature easily, inexpensively and in most of the ways permitted by the laws of physics. This will be essential if we are to continue the revolution in computer hardware beyond about the next decade, and will also let us fabricate an entire new generation of products that are cleaner, stronger, lighter, and more precise.

I agree with the assessment that nanotechnology is one of the most promising and exciting fields of science today. I look forward to working with this committee on its advancement.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

Chairman Inglis and Ranking Member Hooley, thank you for holding this important hearing today. As we all have heard at prior hearings, the emerging field of nanotechnology may lead to unprecedented scientific and technological advances that will benefit society by fundamentally changing the way many items are designed and manufactured. It will take many years of sustained investment for this field to achieve maturity. There is an important role for the federal government to play in the development of nanotechnology, since this science is still in its infancy. This committee, the Congress, and the President all acknowledged that when we enacted the *21st Century Nanotechnology Research and Development Act* in 2003.

The interdisciplinary nature of nanotechnology presents a challenge for the scientific community and the research and development bodies of governments and industry, since it transcends traditional areas of expertise. In addition, nanotechnology will likely give rise to a host of novel social, ethical, philosophical, and legal issues. For these and other reasons, in the legislation this committee required the National Nanotechnology Advisory Panel to report back to the Congress on trends and developments in nanotechnology science and engineering; progress made in implementing the Program; the need to revise the Program; the balance among the components of the Program, including funding levels for the program component areas; whether the program component areas, priorities, and technical goals developed by the Council are helping to maintain United States leadership in nanotechnology; the management, coordination, implementation, and activities of the Program; and whether societal, ethical, legal, environmental, and workforce concerns are adequately addressed by the Program. I am pleased that this report is being released today and that it has found the program is working successfully, although I am troubled by the fact that we are not able to have Floyd Kvamme, Co-chair of PCAST, which is serving as the NNAP, here with us today and urge the Administration to revisit its position on this policy.

It is critical that the United States invests in nanotechnology and does so wisely. Other industrialized countries are already spending more per capita on nanotechnology than the US. Leading nanotechnology researcher Dr. R. Stanley Williams of Hewlett-Packard Laboratories believes that "we are in a global struggle

to dominate the technological high ground, and thus a large portion of the economy, of the 21st Century. The U.S. cannot outspend the rest of the world this time, so we must be by far the most productive at creating new technologies and the most efficient at bringing them to the marketplace. This will require coordination and cooperation across a wide variety of institutions and disciplines such as we have never seen before in the U.S. To fail places the wealth and security of this nation at serious risk." I look forward to hearing the thoughts of these distinguished witnesses about the role the Federal Government should play in helping to commercialize the fruits of its research investments, and the impact this will have on the future of nanotechnology.

[The prepared statement of Mr. Carnahan follows:]

PREPARED STATEMENT OF REPRESENTATIVE RUSS CARNAHAN

Mr. Chairman and Ms. Ranking Member, thank you for holding this important and very interesting hearing.

The creation of the National Nanotechnology Initiative is a program with tremendous vision and I am thrilled to be supportive of the effort.

Nanotechnology has the promise of allowing scientists to control matter on every length scale, including materials in the range of one to 100 nanometers. Science is allowing us to control material behavior by altering structures at the level of one billionth of a meter.

The field includes three main categories of promise, materials and manufacturing, information technology and medicine. I am most eager to see what this technology can do for our nation's health and am hopeful that the utilization of nanotechnology will someday positively affect our economy and job market.

I welcome the witnesses to our subcommittee today and look forward to hearing their testimony. Thank you.

Chairman INGLIS. It is now my pleasure to introduce to you our panel. Mr. Scott Donnelly is the Senior Vice President from General Electric Corporation, we are very pleased to have you, Mr. Donnelly. Dr. John Kennedy is the Director of the Center for Advanced Engineering Fibers and Films at Clemson University in South Carolina. And Ms. Hooley, we are in the right orange category here. I have got on Clemson orange here. Dr. John Cassady, who Ms. Hooley introduced earlier, is the Vice President for Research for Oregon State University. And Mr. Michael Fancher is Director of Economic Outreach at Albany NanoTech. He was very nice to invite me to come see what they are doing, and I suggested that August would be a good time to come to Albany, especially if you are coming from South Carolina in August. Dr. Kennedy will understand that.

So we would be happy to start with your testimony, Mr. Donnelly.

STATEMENT OF MR. SCOTT C. DONNELLY, SENIOR VICE PRESIDENT FOR GLOBAL RESEARCH, CHIEF TECHNOLOGY OFFICER, GENERAL ELECTRIC COMPANY

Mr. DONNELLY. Thank you very much, Mr. Chairman. It is a pleasure to be here to testify with respect to this important technology.

GE's research laboratories have been conducting basic and applied research for over 100 years. It is the primary mission of our research laboratories to investigate, develop new technologies, and most importantly transition those technologies in a consequential way into our General Electric businesses. As a result of the family of product lines in GE, data encompasses a very broad range of technologies in support of energy, aircraft engines, health care, se-

curity, water, and a number of other important commercial fields of interest.

The cornerstone, frankly, of our research laboratories for over 100 years has been materials research. Our materials systems end up impacting in a significant way various different products in GE. As a result, nanotechnology is a very important area of focus for research for us and has been for a number of years.

I think it is very important, the way we look at nanotechnology is not so much in the heart that sometimes is heard or some of the wonderful non-fiction work that has been published, but to recognize the incredible importance of this technology, it truly is a revolutionary way to look at material science and has an amazing number of properties that we think have revolutionized a lot of our GE products.

So when we look at nanotechnology and the importance of this area of research, we really think about how that translates ultimately into our product lines. When we look at businesses like our aircraft engine business of today, for our customers it is very important to drive increasing fuel efficiency and lower emissions, and extending the time between maintenance intervals for our customers is incredibly important, and we look at nanotechnology as a very important way in developing new material systems that have the robust performance features to allow higher firing temperatures, more robust in terms of that their time on wing is very important to the economic model of that whole industry, frankly, and as a result is an important area for us to focus on.

Our energy business is likewise and our conventional gas turbine technologies is very much like aircraft engines. There is a never-ending push for higher efficiencies and lower emissions, lower maintenance cycles, and this technology is very promising in a number of areas.

It is also, we think, a very important technology as we think about renewable energies, things like solar cells and photovoltaics, as a new technology that gives us an additional number of materials to take a lot of very promising new technologies and actually make those technologies economically affordable and therefore increase the penetration of the amount of renewable technology that we deploy across the world.

In addition to energy generation, we look very much at our consumer product lines and how we consume electricity, lighting, and appliances and technologies like that, in which we invest considerably, in our look at how you make those more efficient, how do you introduce new technologies that would replace conventional compression technology, let us say, with thermoelectrics, replace lighting with more highly efficient lighting, reduce things like mercury. All of these kinds of material systems, which for many years, have been dominant in this industry, we actually believe now can be replaced or looked at very differently with the suite of nanotechnology-based materials.

Other increasingly—when we look at our security business, the ability to do things that are very challenging in the security environment, like doing bio-detection of bio-agents in either the air or the water are enabled by a number of new technologies that we are looking at using nano-based labels for these product lines. And we

also think it will have a pervasive impact in our health care business where we looked at both increasing a higher spatial and temporal resolution of our medical scanners, and frankly, introducing a whole new line of product lines and diagnostic pharmaceuticals that allow the targeting of specific biological activities in the body so that we can actually diagnose patients with specific diseases long before they would see symptoms of the disease in total. And a lot of that can be enabled by the use of these nanomaterials to give us the kind of signal that a doctor would look for to make a clinical determination very early on in a disease onset.

So these are all very, very important technologies for us. The research in this area is very, very difficult: identifying new compositions, exploiting those new material systems that give you very robust characteristics that we haven't seen before, and just as importantly, learning how to process those materials. I always like to tell people we don't make nano-sized high pressure turbine blades or nano-sized aircraft engines, and so the ability not just to identify these material properties but to learn the manufacturing process development by which you can make real products and real sizes and maintain the material characteristics that we saw at that nano scale is a very, very challenging task and one that requires a great deal of research, and frankly, time to occur.

The federal role, when we look at what is going on through NNI, the funding for research and development activity and deployment that we see in agencies like the Department of Energy, the Department of Defense, National Institutes of Health, is very encouraging. These are relatively long-time constant technologies, as any material system has historically been, to develop and deploy these. So the Federal Government funding and support of those programs is very important. Frankly, the early adoption is very important to have an opportunity to deploy some of these technologies and get them into the field and learn how to control and manipulate them is very important. The funding that we see that goes through the National Science Foundation to universities is extremely important. In our research laboratories every year, we hire approximately about 100 new Ph.D. students, most of which are conducting research for us in material sciences, and many of them in the field of nanotechnology. The hundreds of graduates at the BS and MS levels that are hired into our GE businesses every year that have to understand and have an appreciation for what these material systems can mean in terms of the design of the next generation of aircraft engine or health care scanner is very important. And so the NSF funding that supports the nanocenters and improvement in those areas is very, very important.

So in summary, nanotechnology is an extremely important technical field to us. It is one in which we are investing a great deal of funding. We are very supportive and appreciate the federal funding that is going into this; both the education as well as deployment through various agencies is very important, and we look forward to continuing to support that activity in the future.

Thank you.

[The prepared statement of Mr. Donnelly follows:]

PREPARED STATEMENT OF SCOTT DONNELLY

Thank you Mr. Chairman, Ranking Member Hooley and Members of the House Research Subcommittee of the Committee on Science.

My name is Scott Donnelly, and I am the Senior Vice President for Global Research for the General Electric Company. I am appearing here today to give you our perspective on the challenges and opportunities in the emerging field of nanotechnology.

The term "nanotechnology" has quickly become one of the latest and greatest buzzwords and can mean different things to different people. At GE, we define nanotechnology as the "ultimate material science," and we believe that the novel material properties found at the nanoscale can be leveraged to create completely new material performance levels for a wide spectrum of products and applications. The focus of our program at GE Research is to leverage these novel properties that are found at the nanoscale and develop methods to build materials from the nanoscale up to the macro world to capitalize on the enhanced performance characteristics demonstrated by these materials.

We believe that nanotechnology has the potential to impact numerous industries. Some examples include:

- Energy, where new materials may enable improved machine efficiency and decreased emissions or enable alternative energy technologies
- Transportation, where the development of new, lighter, stronger materials could increase jet engine efficiency
- Homeland Security, where nanomaterials may lead to improved and faster detection of chemical and biological threats
- Health care, where the development of improved diagnostic agents and equipment may lead to the diagnosis of diseases before symptoms even appear
- Defense applications, where the development of new materials may better protect our soldiers or their vehicles or enable more electric ships.

It is difficult to predict which industries are most likely to be impacted in the near-term and which will be impacted in the longer-term. What is more likely is that in the nearer-term we will see nanotechnology making relatively incremental improvements to currently existing products; such as coatings for plastic and metals, or as additives to existing products. As with all new technologies, it will take longer to realize the truly revolutionary, game-changing technologies that will certainly come from nanotechnology.

What is important to realize, is that this adoption and development route is not unique to "nanomaterials," but is typical for all new material development.

The primary barriers to commercialization of nanotechnology lie in the translation of a scientific innovation to a productive and cost-effective technology. The process of transitioning a successful experiment or even a prototype in a laboratory to a reproducible, high quality, cost effective manufacturing process is a time consuming and expensive hurdle for any invention. And even more challenging with high risk, emerging technologies And in this context it is important to understand that nanotechnology is not an industry, but that it is an enabling technology that will likely impact many industries, but that the challenges and solutions for one area do not necessarily (and probably will not) translate to other sectors.

The barriers to commercializing nanotechnology are not unique and are in fact the same for any new product or application and will require significant time and money—both from private industry and the government—to overcome. In addition, another hurdle nanotechnology will need to overcome as it is commercialized is the need to develop unique manufacturing processes to preserve the novel properties of the nanomaterials. To date there has been a large body of research in nanotechnology that has been done at Universities and there has been a significant effort to establish nano-based centers and user facilities at universities and national laboratories. Much of this has been done as part of the National Nanotechnology Initiative and has provided solid scientific innovation in the field of nanotechnology. In addition, this investment has started to lay the foundation for the nano-workforce that will be required in the future. Scientists and engineers across multiple disciplines, including chemistry, biology, physics, medicine, electronics, and engineering, will need not only to be able to work at the nanoscale but they will also need to have the ability to understand and develop new materials, devices, and systems that have fundamentally new properties and functions because of their nanostructure and because of the convergence of these multiple disciplines. Since GE has it's own corporate research center, we don't typically need the infrastructure provided by the user centers and facilities, and so we have had limited interaction

with these sites. We do collaborate with Universities as part of our nanotechnology program, as well as other research programs, and we have found the NSF Goali program to be a good mechanism for collaborating with Universities.

In closing, the Nation's nanotechnology program is poised to transition to the next phase of it's development. The effort to date has resulted in well-done science, and should continue, but the next phase must also address nanotechnology development—that is making nanotechnology a reality, so that the full economic potential of nanotechnology and the benefit to the Nation can be realized.

Thank you Mr. Chairman for the opportunity to testify today, and I welcome any questions.

BIOGRAPHY FOR SCOTT C. DONNELLY

Scott C. Donnelly is Senior Vice President and Director of GE Global Research, one of the world's largest and most diversified industrial research organizations, and a member of the company's Corporate Executive Council. At Global Research, some 2,200 people—including approximately 1,700 scientists, engineers and technicians from virtually every major scientific and engineering discipline—concentrate their efforts on the company's long-range technology needs. The organization has research facilities in the United States, India, China and Germany, working in collaboration with GE businesses around the world.

Prior to assuming his current position, Donnelly served as Vice President, Global Technology Operations for GE Medical Systems. In that role, he drove Six Sigma product development throughout the organization, enabled GE Medical Systems to introduce more reliable technology faster than ever before, including: the world's first multi-slice CT scanner (LightSpeed), full-field digital mammography (Senographe 2000D), high-field open MRI (Signa OpenSpeed) and digital X–Ray (Innova 2000).

Donnelly joined GE in 1989 as Manager of Electronics Design Engineering for GE's Ocean Systems Division in Syracuse, NY. He went on to serve in a variety of leadership roles for the Company, including engineering management positions with then-GE division of Martin Marietta in both Australia and the U.S.

In 1995, he moved to GE's Industrial Control Systems business, where he held leadership positions as Manager of Technology and System Development, and later General Manager of Industrial Systems Technology. Donnelly was named a Vice President of General Electric in 1997, when he assumed his previous role at GE Medical Systems.

Donnelly is a 1984 graduate of the University of Colorado at Boulder, where he earned a Bachelor's degree in Electrical and Computer Engineering.

Donnelly serves on the Industrial Advisory Committee of several engineering colleges, the Research Foundation of the Medical College of Wisconsin and the Center for Innovation in Minimally Invasive Therapy at Massachusetts General Hospital. He also serves as a Director of GE Capital Corporation and GE Capital Services Inc.

May 13, 2005

The Honorable Bob Inglis
Chairman, Research Subcommittee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Inglis:

Thank you for the invitation to testify before the Research Subcommittee of the Committee on Science of the U.S. House of Representatives on May 18th for the hearing entitled "***The National Nanotechnology Initiative: Review and Outlook***." In accordance with the Rules Governing Testimony, this letter serves as formal notice of the federal funding that GE Global Research currently receives that is related to our nanotechnology program (Table 1)

Amount	Grant Number	Agency	Title	Date received
$5,783,668	70NANB2H3030	NIST-ATP	Template Synthesis Platform for Nanostructured Materials	November 2002
$3,179,360	DEFC2603NT41945	DOE-NETL	Novel Nanophosphors for High Efficiency Fluorescent Lamps	September 2003
$2,420,254	HSTS0404GRED940	TSA	Stationary X-ray Source Technology for Next Generation Explosive Detection Systems	September 2004
$4,078,587	DE-PS26-04NT422113	DOE (1)	Direct Energy Conversion from Waste Heat Recovery	2005 (2)
$520,000 (3)	DE-PS26-04NT42249	DOE-NETL	Development of Technologies and Capabilities for Coal energy Resources	2005 (2)
$3,000,000 (3)	Pending	DOD-TACOM	Nano-Engineered Materials for High Performance Armor	2005 (2)

(1) Subcontractor to General Motors
(2) Expected—currently under negotiation
(3) Approximate value—contract pending

Sincerely,

Scott Donnelly, SVP
GE Global Research

Chairman INGLIS. Thank you, Mr. Donnelly.
Dr. Kennedy.

STATEMENT OF DR. JOHN M. KENNEDY, DIRECTOR, CENTER FOR ADVANCED ENGINEERING FIBERS AND FILMS, CLEMSON UNIVERSITY

Dr. KENNEDY. Good morning, Chairman Inglis and Ranking Member Hooley. Greetings from South Carolina, Clemson University.

Clemson University continues to climb in the national rankings, which bodes well for the State of South Carolina and its drive toward a knowledge-based economy.

On behalf of the Center for Advanced Engineering Fibers and Films representing Clemson University, our university partners MIT, Clark Atlanta University, and supporting industries, I would like to thank the Committee for inviting me to testify.

The National Nanotechnology Initiative provides a systemic program for helping the United States maintain its research and technical leadership in an increasingly competitive global environment. I am pleased to be here to provide CAEFF support for the initiative.

CAEFF is one of 22 engineering research centers funded by the National Science Foundation. We provide an integrated research and education environment for the systems-oriented study of fibers and films. CAEFF promotes the transformation from trial-and-error development to computer-based design. The industry partners provide practical perspective on our research program. For these industries to leverage advances at the nano level, computer-modeling techniques that maximize engineers' understanding of and control over structure are required.

The CAEFF team is very active in nanotechnology research. We are studying carbon nanotubes for bio-sensors, filtration, bio-compatibility, coatings, and infection prevention. We are also exploring nanotechnology to improve wound and incision healing and as a means for hydrogen storage. CAEFF supports a critical component of the U.S. manufacturing base.

However, globalization is changing this industry. A significant portion of the commodity fiber industry has relocated outside of the United States. The polymer industry is adjusting, however, to globalization by focusing on value-added products, which ties well to the push for an economy driven by innovation.

CAEFF is focusing its research on six product areas: carbon products for transportation, bio-based polymers, bio-inspired polymers, fibers and films for biotechnology, photovoltaic films, and sensing films. Each area supports specific commercial products that could help reshape the polymer industry. CAEFF derives its support from four sources: the base NSF-ERC grant, the State of South Carolina, industry membership fees, industry-supported research, and other federal support. The collective support for CAEFF has been outstanding, enabling us to be positioned as a national leader in polymer research.

CAEFF is training a new workforce to develop nano-based applications. A team of universities led by our center is developing an undergraduate, macro-molecular engineering curriculum that addresses design at the molecular level. This exciting concept will combine features of materials science and engineering so that grad-

uates can consider molecular or nano issues in the design of new value-added products.

Another workforce issue is the supply of American citizens involved in nano research. One goal of CAEFF is to develop a diverse community of scholars trained in polymeric materials design. We are making great progress. The center has formed a partnership with Clark Atlanta University to increase the participation of African American faculty and students. Diversity in the center is also fostered by outreach through Women in Science and Engineering, the Girl Scouts, summer research, graduate assistantships in areas of national need, Hearst Fellowships, and the newly-funded Southeast Alliance for Graduate Education and the Professoriate.

Our graduates are entering the workforce as engineers and scientists in the polymer industry. Many of them have taken jobs with our industry partners. Several have chosen to enter academe.

The National Nanotechnology Initiative provides significant support for infrastructure, faculty, and students. As various components of the research mature, the challenge will be to transfer the technology into profitable business ventures. It is likely that an entirely new industry will be spawned from nanotechnology. This new industry will be comprised of small businesses that are exploiting research advancements. For these companies to survive, they may well need bridge funding.

To accelerate the application of nanotechnology, agencies that have a major stake in applied research and development can bring nanotechnology into practice through demonstration programs. This paradigm was used successfully by NASA and DOD to accelerate the application of advanced composite materials 25 years ago. These programs were partnerships between government and industry that drove industry to educate its personnel, develop infrastructure, and validated the advantages afforded by composites.

Thank you for inviting me to testify before your Subcommittee today. I am fully supportive of the National Nanotechnology Initiative. It is a critical initiative with huge potential to impact the citizens of the United States. I would be glad to answer your questions.

[The prepared statement of Dr. Kennedy follows:]

PREPARED STATEMENT OF JOHN M. KENNEDY

Introduction

Good morning, Chairman Inglis and Ranking Member Hooley. Greetings from South Carolina and Clemson University. Clemson University continues to climb in the national rankings which bodes well for the State of South Carolina and its drive toward a knowledge-based economy. On behalf of the Center for Advanced Engineering Fibers and Films (CAEFF), our university partners (the Massachusetts Institute of Technology and Clark Atlanta University), our 20 industry partners, and Clemson University, I would like to thank the committee for inviting me to represent CAEFF at this hearing. The National Nanotechnology Initiative provides a systemic program for helping the U.S. maintain is research and technology leadership in the increasingly competitive global environment. I am please to be here to provide CAEFF's support of the Initiative.

The Center for Advanced Engineering Fibers and Films (CAEFF) is one of only 22 Engineering Research Centers funded by the National Science Foundation. The CAEFF research team consists of faculty and students from nine academic departments at Clemson University (the lead institution), MIT (a core partner), Clark Atlanta University (a core partner), Lehigh University, McGill University, the University of Illinois, and 20 industry partners. CAEFF provides an integrated research and education environment for the systems-oriented study of fibers and films.

CAEFF promotes the transformation from trial-and-error development to computer-based design of fibers and films. This new paradigm for materials design is revolutionizing fiber and film development.

The NSF began funding CAEFF in 1998 and funding will continue through 2008, with research expenditures approaching $10 million annually. About 150 graduate students, 75 undergraduates, 15 high school students, and 50 faculty members support CAEFF's research program. Coordinated with CAEFF's research is an education program that is offering innovative multi-disciplinary courses, seminars, short courses, and workshops. The education experience is further enhanced by activities that emphasize teamwork and communication skills. CAEFF promotes diversity in its research team through scholarships, fellowships, and collaboration with universities that serve under-represented populations.

CAEFF is a cornerstone of Clemson University's research program. Several research niches, particularly nanomaterials, fall under CAEFF, and other developing research programs have been incubated in CAEFF. After 2008, CAEFF will be a self-sufficient research enterprise through additional government and foundation funding, industry sponsorship, and royalties from intellectual property.

Nanotechnology-Related Research

The CAEFF team is very active in nanotechnology research that can potentially advance technology and impact our citizens' health and well being. Our researchers are using carbon nanotubes (highly ordered carbon structures) for biosensors, filtration, biocompatible coatings, and infection prevention. We are also exploring nanotechnology as a means for improving healing from surgery and wounds. Controlling cell growth through optimally changing the texture at the nano-level of sutures and meshes will strongly influence healing and repair of living tissue as in a hernia repair.

We have also discovered that activated carbon fibers (carbon fibers with nano-sized pores) can be used to achieve 30 percent of the Department of Energy hydrogen storage target at room temperature and moderate pressure.

Adding nanoparticles to fibers dramatically improves the cut resistance of the fibers. Consequently, we are presently working with a company to exploit this technology for protective clothing that would improve workers' safety. This technology could be useful for police officers, workers that process food or handling sharp materials such as glass or sheet metal, or our infantry.

These areas point to nanotechnology that is being or is close to being applied in a commercial venture. However, CAEFF is also conducting fundamental research that provides results in new knowledge that may have impact on the way we make fibers or assembly materials. One of our research groups is trying to mimic the way spiders make fibers because spiders have optimized the fiber spinning process. They make a fiber with excellent properties at about room temperature and atmospheric pressure. Also, spiders do not use oil as the feedstock which is used for over 99 percent of all man-made fibers. All of the man-made fibers require various combinations of high temperature, high pressure, and toxic solvents. If we could mimic the process that spiders use to make fibers, then we could potentially develop processes that are less energy intensive and environmentally friendly.

We have also learning how to assemble molecules. Once we know how to do this, we will be able to sense, capture, and destroy toxins. This technology could be applied to provide healthier hospitals and security against bio-terrorism.

Another research group has learned how to blend materials to produce nanolayers. This technology has been termed smart blending. The implications of this technology are tremendous, so much so, that patents have been issued, several companies have licensed the technology and many more are interested. With smart blending, plastic parts have improved strength, food packaging prevents spoilage better, and static build up in plastic parts is minimized. We are just beginning to tap the potential of this exciting technology.

Interaction with Industry

NSF Engineering Research Centers (ERC), like CAEFF, are required to have industrial partners on the research team. These partners help the ERC define the systems-level research program which is the key characteristic of an ERC. Systems-level research occurs on three planes—fundamental knowledge, enabling technology, and engineered system. Clearly, the industry partners provide practical perspective on what fundamental knowledge is needed, the technology that must be developed to make the research advancement a viable commercial product, and the experience to package the technology into a system for commercialization.

By focusing on fiber and film technology, CAEFF supports a critical component of the U.S. manufacturing base. The fiber and film industries provide the consumer

with synthetic fibers, nonwoven fabrics, multi-layer films, flexible packaging, and state-of-the-art electronic components—just to name a few of its products. When CAEFF was selected as an NSF Engineering Research Center in 1998, economic projections indicated that the fiber and film industries could grow by 50 percent over the next ten years—if they responded to the needs of their customers by improving existing products, developing new products for future markets, and instituting more efficient, environmentally friendly processes. If it was apparent then that traditional research and development practices, basically a trial and error approach to product and process development, had not produced the breakthroughs necessary to revitalize these industries so crucial to our quality of life, today it is glaringly evident. A significant portion of the commodity fiber industry has relocated outside of the U.S. to take advantage of lower labor costs and to be close to the textile industry that they supply. Industry-wide restructuring has changed the operating philosophy of many major producers, who have increased profitability by reducing research and technical support. This point is driven home by the shift of polyester production from the U.S., Europe, and Japan to China, Japan and India and, closer to home, the regular announcements of textile plant closings in the southeast. However, the polymer industry is adjusting to globalization by focusing on value-added or "niche" products and on products that are not labor intensive such as carpet and consumables. Development of value-added products ties well to the push for an economy driven by innovation.

Since its inception, CAEFF's mission has been to arm industry with a unique modeling tool to design fiber and film processes and predict final properties of the fiber or film product. This modeling capability provides industry with the knowledge, in a user-friendly software package, to develop innovative fiber and film products. Some of our industry partners are using this capability in designing processes for new polymers. It is our belief that the fiber and film industries need to develop products and processes in advanced engineering environments that use computer modeling techniques and visualization to minimize experimentation, allow manipulation of both molecular and continuum information, and maximize engineers' understanding of and control over structure formation and resultant properties. The properties of films and fibers depend on their polymeric structure. In nearly all commercial fiber and film processes, this structure is created by the production process.

In response to these industry and societal needs, the Center has developed a materials design environment, featuring an integrated model that allows users to design an entire fiber or film system by inputting precursor specifications, processing parameters, and desired properties. This virtual testbed will bring design improvements to current manufacturing systems, and also significantly reduces, if not alleviates trial-and-error experiments needed for the design of next-generation fiber and film processes.

Given the evolution of our research and the emerging needs of industry, CAEFF revised its strategic research plan in the last year. The primary change to the strategic plan was to establish six systems-level product areas that complement the multi-length scale modeling effort that is the cornerstone of the vision and strategic plan of CAEFF. Each of the product areas supports an opportunity for the polymer industry to develop value-added products. CAEFF is uniquely position to conduct research in these product areas because each requires cross-disciplinary teams to make substantive systems-level research advancements. The six product areas were selected because they focus the modeling efforts on specific commercial products that could help reshape the polymer industry as globalization drives production of conventional fibers and films offshore. The research will enable industry to shorten the cycle from concept to commercialization.

CAEFF presently has 20 industry partners that support our research with directed and undirected financial support and in-kind support. Our members represent a broad spectrum of companies from large to small and producer to user. The logos of our industry partners are shown on the chart below. Each member pays a membership fee that CAEFF management strategically directs to research, equipment and management. Some companies choose to provide additional funding for research specific to their needs. In this case, the company defines the research project. In many cases a confidentiality agreement is executed so that the company can exploit the results of the research that they sponsored.

Our industrial collaboration, including transfer of intellectual property, is governed by a common CAEFF Membership Agreement that all companies must execute. The Membership Agreement provides each industry partner a seat on the Industrial Advisory Board (IAB). The IAB is the body that provides industry guidance on research direction and policy as discussed above. A primary function of the Membership Agreement is the transfer of intellectual property. The intellectual property policy in the Agreement is structured to favor licensing by industry partners. The following flow chart shows the licensing process that is called out in the Agreement. The key features of the intellectual policy are: an industry sponsoring research has first rights to a license resulting from their project; intellectual property resulting from research funded by NSF, the State, or other federal agencies will be offered to all of the industry partners; and CAEFF will place industry-experienced personnel on the committee that determines which intellectual property will be patented by Clemson University.

The two greatest barriers to academic/industrial cooperation are the elimination or drastic reduction of central research and development staff in large companies and the existence of companies that have the vision to exploit new nanotechnology developed by CAEFF.

Support for CAEFF and Self Sufficiency

CAEFF derives its support from four sources: the base NSF ERC grant (currently about $3.8 million annually), the state of South Carolina ($1.0 million annually as cost share for the NSF ERC grant), industry membership fees (approximately $150,000 annually), industry supported research ($250,000 annually), and other federal support routed through CAEFF ($3.6 million annually). When CAEFF was in the formative stages the state and Clemson University provided even more support for renovation of space and salary support for CAEFF leadership to develop the research and education program. Additionally, the state has provided funding for the design and development of a new academic building on the Clemson campus for CAEFF and the School of Materials Science and Engineering. Construction of the building will commence when the next bond bill is approved by the South Carolina legislature.

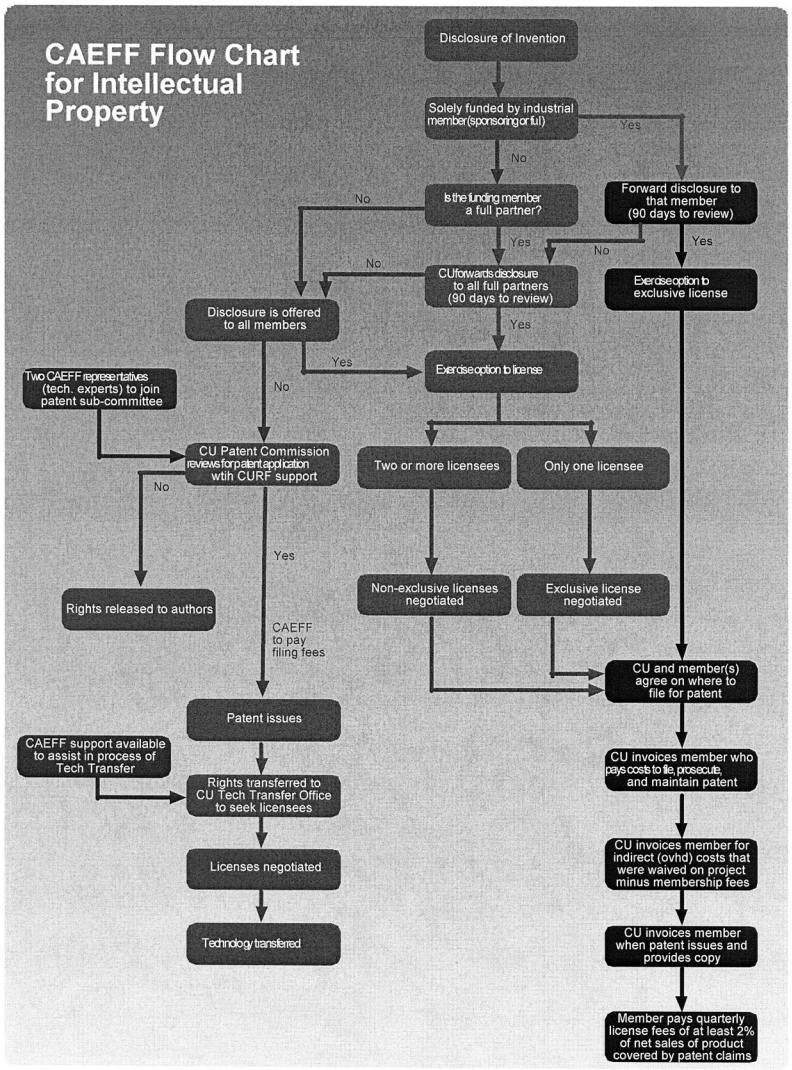
These funds can be divided into five broad categories: research, education, industry liaison, equipment, and management with the largest portion going to research, followed by education and equipment. Generally, the support for industry directed research his highly compatible with the research supported by NSF. We have used our modeling capability and experimental testbeds, developed with NSF support, on numerous industry sponsored projects.

The support for CAEFF from NSF and the state has been outstanding, enabling us to be positioned as a national leader in polymer research. Professor Mike Jaffe (New Jersey Institute of Technology and former employee of Hoechst Celanese Corporation,) has suggests that CAEFF provides "World leadership in modeling at

Clemson CAEFF ERC." Without the NSF ERC and State support, the claim would not be possible. The NSF support for CAEFF will terminate in July 2008 as per ERC guidelines. CAEFF leadership is developing a strategic plan to assure that the NSF support will be replaced with funding from other resources.

Workforce Development for Nanotechnology

For the most part, the workforce and those entering the workforce in the nanotechnology area have received traditional engineering or science educations which do not provide a systems perspective related to nanotechnology. This perspective is crucial for companies because virtually all nano-based applications are multidisciplinary, requiring the talents of scientists and engineers from several disciplines. Further, most engineering programs teach design at length scales that are much greater than the nanoscale.



The Center is graduating students with a broad, systems-oriented technical foundation; modeling, simulation, and visualization skills; the critical thinking skills necessary to both analyze and integrate information; an appreciation of the industry perspective; and the teamwork and communication skills necessary to function effectively in collaborative virtual design environments. CAEFF's integrated research and education programs have developed advanced materials design techniques that are communicated through courses, workshops and conferences, and outreach programs.

CAEFF is working with a team of universities to develop an undergraduate macromolecular engineering curriculum that addresses design at the molecular level. This exciting concept will essentially bring together features of a materials science curriculum and those of engineering disciplines such as chemical and mechanical so that graduates will have background to consider molecular or nano issues in the design of systems. Adding molecular level considerations to the design process will expand the design envelope, leading to new value-added products in transportation, medicine, defense, and national security.

Thirty-three percent of South Carolina's population is minority, principally African-American, the opportunity exists to greatly increase the diversity in both the student body and the faculty. For the population of South Carolina's Land Grant University to reflect the demographics of the state, a long-term, well funded educational program must be implemented at all societal and educational levels in South Carolina so that all students realize the importance of higher education and have prerequisite academic credentials and/or enter into bridge programs that give them the opportunity to succeed in the rigorous academic environment of engineering and science disciplines. Consequently, the goal of CAEFF became to develop a diverse community of scholars trained in polymeric materials design. The various populations (pre-college, undergraduate, graduate and faculty) of this community of scholars will mirror the demographics of the State of South Carolina. Meeting this overall metric was very aggressive and will substantially exceed national engineering-wide averages for the involvement of women, under-represented racial minorities, and Hispanic-Americans. We are approaching our goals for under-represented racial minorities in our undergraduate and masters student populations. Outlined below are the components of CAEFF's diversity program.

The Center has formed a partnership with Clark Atlanta University (CAU) to increase the participation of African-American faculty and students in the research and education programs of CAEFF. A research contract was awarded to CAU for the remainder of CAEFF's NSF lifetime. Faculty members and students from CAU are being integrated into CAEFF's research topics as core members of the research teams. CAU is being targeted to provide undergraduate and graduate students to CAEFF's programs at Clemson University. Our intent is to develop a dual degree program with CAU.

Diversity in the Center has been fostered by outreach through Women in Science and Engineering, the Girl Scouts of the USA, and the Research Experiences for Undergraduates program. The Center has also secured supplemental funding to support diversity initiatives. Department of Education-funded Graduate Assistantships in Areas of National Need provide attractive financial incentive packages to minority and female students of superior academic ability from across the Nation. The Hearst Scholarship endowment targets a diverse, academically qualified and economically disadvantaged student population. The newly-funded Southeast Alliance for Graduate Education and the Professoriate will provide a mechanism for recruiting students from the University of Florida, the University of South Carolina, and the University of the U.S. Virgin Islands. This grant will also provide international opportunities for students through collaboration with the Latin American and Caribbean Consortium of Engineering Institutions.

Our graduates are entering the workforce as engineers and scientists in the polymer industry. Many on them have taken jobs with our industry partners. Several have chosen to enter academe.

The Federal/State/Industry/Academe Nanotechnology Partnership

The National Nanotechnology Initiative provides significant support for infrastructure, faculty, and students. As various components of the research mature, the challenge will be to transfer the technology in to profitable business ventures. It is likely that an entirely new industry will be spawned from the nanotechnology initiative. This new industry will probably be comprised of small businesses that fit a niche or are exploiting research advancements. For these small companies to survive, they may well need bridge funding which can be made available through the Small Business Innovative Research and Small Business Technology Transfer Pro-

grams, available from all federal agencies, and also the Advanced Technology Program which is run through the National Institute of Standards and Technology.

To accelerate the application of nanotechnology and to identify unforeseen issues surrounding nanotechnology systems, agencies that have a major stake in applied research and development such as NASA, the Department of Defense, and the Department of Transportation can bring nanotechnology into practice through demonstration programs. This paradigm was used successfully by NASA and the Department of Defense to accelerate the application of advanced composite materials in the 1970's and 1980's. These programs were partnerships between government and industry that drove industry to educate its personnel and develop infrastructure. It also provided validation of the advantages afforded by composites. Finally, after 20 to 25 years, advanced composites are being extensively used on commercial aircraft for major structural components. This large time lag was predictable because industry needed time to train a workforce, establish design methods, and build a database, all of which are required for confident application of composites in complex systems and structures.

Closure

Thank you for inviting me to testify before your subcommittee today. I am fully supportive of the National Nanotechnology Initiative. It is a critical initiative with huge potential to impact the citizens of the U.S. I would be pleased to answer your questions.

CENTER FOR ADVANCED ENGINEERING FIBERS AND FILMS
A National Science Foundation Engineering Research Center

May17, 2005

Congressman Bob Inglis
Chairman, Research Subcommittee
of Science Committee
House of Representatives
Washington, DC 20515

Dear Chairman Inglis:

Please find attached the official Current and Pending Support Form that outlines the federal support that I receive to perform my duties as Director of the Center for Advanced Engineering Fibers and Films and Campus Director of the South Carolina Space Grant Consortium that is funded by NASA.

Sincerely,

John M Kennedy

John M. Kennedy, Ph.D.
Director

301 Rhodes Engineering Research Center Clemson University Clemson, South Carolina 29634-0910
Voice (864) 656-1182 Fax: (864) 656-4557 E-mail: caeff@ces.clemson.edu Internet: www.clemson.edu/caeff

Status: Current	Proposal #10734
Title	*Center for Advanced Engineering Fibers and Films*
Sponsor	NSF
Location of Project	Clemson University
Total Award Amount	$12,000,000
Total Award Period Covered	8/98-8/06
Person-Months per year	
P.I./Co-P.I.	P.I.

Status: Current	Proposal #2004000538
Title	*Campus Director Funds – SCSGC*
Sponsor	NASA
Location of Project	Clemson University
Total Award Amount	$4,640
Total Award Period Covered	3/1/04 – 2/28/05
Person-Months per year	
P.I./Co-Inv.	P.I.

Status: Current	Proposal #2004000708
Title	*Research Experiences for Undergraduates in the Center for Advanced Engineering Fibers and Films*
Sponsor	NSF
Location of Project	Clemson University
Total Award Amount	$189,000
Total Award Period Covered	06/01/05-09/01/08
Person-Months per year	
P.I./Co-Inv.	P.I.

Chairman INGLIS. Thank you, Dr. Kennedy. We look forward to those questions.

Dr. Cassady.

STATEMENT OF DR. JOHN M. CASSADY, VICE PRESIDENT FOR RESEARCH, OREGON STATE UNIVERSITY

Dr. CASSADY. Chairman Inglis, thank you for holding this hearing on the National Nanotechnology Initiative. It is a privilege to be invited to testify before you this morning not only as a representative of Oregon State University and the Oregon Nanoscience and Microtechnologies Institute, ONAMI, but also as a scientist interested in the intersection of research and economic development.

I also want to acknowledge how pleased we are at Oregon State that our representative, Congresswoman Darlene Hooley, is now serving as the Ranking Minority Member on this Research Subcommittee.

I want to acknowledge the assistance of the leaders of ONAMI at Oregon State, the Dean of Engineering, Ron Adams, and the Director of ONAMI, Skip Rung, for input to this testimony.

My perspective is not as an expert in the area of nanotechnology, but as a person trained in organic chemistry who moved into the interdisciplinary area of medicinal chemistry and was involved during my research career in the discovery and design of potential anti-cancer drugs. Nanotechnology touches health in a major way, and eventually will have a major impact in the area of diagnostics as well as drug delivery.

As a faculty member, department chair, dean of a college of pharmacy, and now the new Vice President for Research at Oregon State, I have promoted programs that are interdisciplinary and translational, so one of the things that attracted me to Oregon was the Oregon experiment in innovation that led to ONAMI.

Oregon is a small state, but it is thinking and planning in a big way as it moves in the direction of a commercialization alliance in micro and nanotechnology. All of the components were there in 2000, but they weren't aligned. There were institutional resources, our state's public research universities, Oregon State, University of Oregon, and Portland State, powerful research enterprises, the industrial infrastructure, companies comprising the Oregon "Silicon Forest," Intel, HP, FEI, LSI Logic, Xerox, Tektronix, ESI, InFocus Systems, Pixelworks, Sharp, and many others.

Another strength was our regional government laboratory, Pacific Northwest National Laboratory, PNNL. Then in 2002, an economic development report was commissioned by the state, which recommended the development of signature research centers. In 2003, the Oregon State legislature created the Oregon Nanoscience and Microtechnologies Institute, ONAMI, with an initial allocation of $21 million for support of operating costs and infrastructure.

The state began a commitment to make innovation a high priority. The research universities, the high-tech industries, and PNNL joined together in aligned missions in a national model for collaboration.

Let me describe one of the partnerships developed at Oregon State to create the Microproducts Breakthrough Institute, MBI. This institute, which is housed in a building on HP's campus, is a result of a collaboration between OSU and HP, which has donated the lab space, and PNNL, which is providing support through research collaborations and scientific personnel that are assigned to the project. When the institutes' laboratories become operational this year, up to 10 PNNL research staff are projected to be located at MBI in addition to faculty and students from OSU.

Additional support from the state is expected, and this initial investment has leveraged over $5 million in support from the universities, $10 million from industry and private funding, and more than $30 million in competitive research awards. This cooperative venture is unprecedented and will lead to talented graduates, new technology, and corporate development.

There are some barriers to collaboration. Some of these are cultural. On the academic side of the house, I think it is acceptance of new metrics for academic excellence and our reward system. On the corporate side of the house, control of intellectual property rights and confidentiality limitations are what lead to what I consider to be non-transparent communications, in addition, rapid

changes in funding decisions, personnel changes, and corporate structure.

Some of the barriers to protection, transfer and commercialization are lack of investment funds for IP protection, lack of gap funding for product development, and developing processes to make it easier to start businesses in the university.

We also need to make it easier to do business with the university and streamline our IP licensing. There are workforce issues. There is an impact on graduate programs due to security issues, and we need to keep the funding for research and graduate programs a priority.

In order to facilitate advances in these areas, one possible solution is to establish federal funding sources that set clear objectives related to translation of technology and economic development, put in place metrics to measure progress against these goals, and hold recipients accountable for funding for achieving these outcomes.

It is the people of Oregon and the Nation that will benefit from programs like ONAMI. From individuals who can take advantage of such devices as compact portable home kidney dialysis devices to communities which experience economic prosperity with the establishment of new nanotechnology businesses and industry.

In conclusion, I wish to thank you for this opportunity. Nanotechnology is an exciting new area, which will have tremendous impact across multiple fields of science. We are excited that in Oregon we have been able to develop a vision for significant partnerships, such as ONAMI, and that private, state, federal, and university investments have made the vision a reality.

Thank you.

[The prepared statement of Dr. Cassady follows:]

PREPARED STATEMENT OF JOHN M. CASSADY

Chairman Inglis, thank you for holding this hearing on the National Nanotechnology Initiative. It is a privilege to testify before you this morning, not only as a representative of Oregon State University (OSU) and the Oregon Nanoscience and Microtechnologies Institute (ONAMI), but also as a scientist interested in the intersection of research and economic development. I spent nearly forty years an academic research scientist and only recently closed my laboratory at Ohio State University to take the post of Vice President for Research at Oregon State University. I am very excited about the opportunity to oversee the OSU research enterprise and to work toward ensuring that innovation at the lab bench contributes to public life, be it through public education, outreach and engagement or business and industry. I also want to acknowledge how pleased we are at Oregon State University that our Representative, Congresswoman Darlene Hooley, is now serving as the Ranking Minority Member on this Research Subcommittee.

My testimony to you this morning comes from the perspective of a research administrator. I am an organic chemist and spent most of my research career focused on the discovery and design of anticancer drugs; I am not an engineer by training nor am I an expert in nanotechnology. However, what I can speak to is the desire of researchers to ask questions and solve problems and what I believe is my responsibility as a research administrator to direct these questions in a way that works to sustain the Nation's economic development and global technological leadership, builds an educated workforce, and contributes to public health and security.

I believe these were all goals in the development of the National Nanotechnology Initiative, which was envisioned as a roadmap for the Federal Government's investments in a critical area of science. In Oregon, we, too, kept these goals in mind as we mapped out our plan to be a part of this scientific revolution and designed a research institute that created innovative new partnerships that cross university, government and industry boundaries that have not previously been formally connected.

Three words describe ONAMI: innovation, collaboration, and commercialization. The Oregon Nanoscience and Microtechnologies Institute is the first "signature research center" funded by the State of Oregon for the purpose of growing research and business development in order to accelerate innovation-based economic development in Oregon and the Pacific Northwest. Oregon policy-makers have the goal and desire to establish additional "signature research centers" that will lead to a long-term economic and competitive advantage for Oregon, including commercialization of academic research and the formation of new businesses.

ONAMI is also an unprecedented and powerful collaboration involving Oregon's three public research universities—Oregon State University, Portland State University, and the University of Oregon; the Pacific Northwest National Laboratory (Richland, WA); the State of Oregon; and the emerging "Silicon Forest" high technology industry cluster of Oregon and southwest Washington.

Many factors precipitated this focus on nanotechnology in Oregon. Businesses in Oregon were already leaders in industrial research and development. Intel employs 15,450 employees in Oregon and is the home of the headquarters of their semiconductor technology research and development unit. Hewlett Packard's Ink Jet headquarters are in Oregon and the company's largest and most advanced technology site with 3,900 employees is also located in the state. FEI Company, LSI Logic, Tektronix, Xerox, Invitrogen, InFocus, Pixelworks and Electro Scientific Industries are just a few of the many other technology-based industries with a significant presence in the state. Our proximity to the Department of Energy's Pacific Northwest National Laboratory (PNNL) was also a factor. PNNL, a $650 million year research operation is the largest R&D operation west of Chicago and north of San Francisco. And, last, but certainly not least, Oregon's three largest research universities have world-class expertise and have decided to collaborate in three critical areas: Microtechnology-Based Energy, Chemical and Biological Systems; Safer Nanomaterials and Nanomanufacturing and Nanoscale Metrology for Nanoelectronics and other applications.

Microtechnology-based Energy, Chemical and Biological Systems, led by Kevin Drost of Oregon State University and Landis Kannberg of the Pacific Northwest National Laboratory, integrate nanoscale materials science and mechanical microstructures to miniaturize a wide range of important devices for both military and commercial use. Translational research and commercialization efforts related to this work will be carried out by the Microproducts Breakthrough Institute (MBI), an ONAMI facility jointly staffed and operated by PNNL and Oregon State University.

These technologies will have widespread commercial application and may well lead to whole new industries. Examples include compact power supplies for portable electronics; vehicular and auxiliary fuel cell systems; distributed biofuel, hydrogen, and chemical production at point-of-use; automotive cooling systems that operate using exhaust heat; and a new generation of distributed heating and cooling systems for residences with energy savings of approximately 50 percent. OSU researchers in this area are also working with an Oregon company, Home Dialysis Plus (HD+), to develop a compact kidney dialysis machine that will dramatically improve quality of life for end-state renal disease patients while also reducing treatment cost.

The Safer Nanomaterials and Nanomanufacturing research, led by Jim Hutchison of the University of Oregon, is focused on developing functional nanomaterials and nanomanufacturing methods that simultaneously meet the need for high performance materials, protect human health and minimize harm to the environment. This initiative has been focused on the applications of mixed nanoscale and microscale systems to research problems such as those involved in nanomanufacturing. The initiative takes advantage of the world-class expertise within ONAMI in green chemistry, nanoscale materials and processes and the design and fabrication of microscale systems (such as microchannel reactors).

Discoveries in nanoscience are providing new, powerful tools for achieving green chemistry goals such as reducing the use of hazardous materials and improving the efficiency of material and energy consumption. The opportunity exists to apply nanotechnologies to the invention of new products and processes that will produce superior products for less money and simultaneously enhance public security and protect our environment. Researchers within the ONAMI are at the forefront in defining this emerging field with their research programs that focus on safer/greener products *and* manufacturing methods for making products.

The Nanoscale Metrology Initiative, critical to continued progress in semiconductors and other forms of nanoscale manufacturing, is led by John Carruthers, former Director of Components Research and Development for Intel, and Distinguished Professor of Physics at Portland State University (PSU). The team's efforts are supported by the PSU microscopy facility, which features one of the Pacific Northwest's

most powerful transmission electron microscopes and other instruments that enable the characterization of nanostructures. The ability to design, fabricate and test nanoscale materials and devices depends entirely on the ability to image and measure them, which the network of ONAMI-affiliated user facilities can provide.

The purpose is to initiate additional research in nanometrology and testing of nanodevices and circuits that enables the implementation of nanoscale materials into useful electronic applications such as high density memories on silicon integrated circuits.

This will leverage the large nanotechnology-related investments of LSI Logic, Nantero, Intel, Hewlett-Packard, ESI, FEI Company, and Invitrogen in Oregon's "I–5 Technology Corridor" between Portland and Eugene and ensure that a leading edge research and education capability will be established to further grow the global competitiveness of the nanotechnology industries there.

All of these ONAMI partners came together with several goals in mind: to attract federal research investments in the Oregon and Pacific Northwest; to provide an outstanding collaborative environment for researchers who are at the forefront of innovation in their fields; to increase the impact of this research on Oregon industry; to develop superior workforce talent—especially growth in Ph.D.s; and to spin out the innovations and new companies that will provide the high-wage jobs of the future.

At your request, I am providing to you today responses to the questions you posed examining the challenges and opportunities related to nanotechnology, based on our experiences at Oregon State University and with the Oregon Nanoscience and Microtechnologies Institute (ONAMI).

- **How do Oregon State University (OSU) and the Oregon Nanoscience and Microtechnologies Institute (ONAMI) interface with the private sector? What are the greatest barriers to increased academic/industrial cooperation in nanotechnology?**

In Oregon, the cooperation OSU and our other academic partners have with private sector via ONAMI is unprecedented. Perhaps most notably, Hewlett-Packard developed a very comprehensive inter-institutional agreement with OSU. As a part of this partnership, HP donated the use of a building on their campus in Corvallis, Oregon to accelerate the startup facility. This was a remarkable display of corporate citizenship. This facility serves as a product development space for new ONAMI-related companies while the three universities complete construction of additional ONAMI research facilities. HP donated the three-year lease of the building, valued at $2 million. The construction of new facilities, currently underway, is primarily funded through gifts and state appropriations.

ONAMI Board members include senior executives from some of the world's leading nanotechnology companies: Hewlett Packard, FEI Company (the world leader in tools for nanotechnology, based in Hillsboro, Oregon), LSI Logic and Nantero (a partnership with a focus on nanotechnology-based semiconductor memory development, based in Gresham, Oregon), Pixelworks (the fourth fastest growing company in the U.S.), and Battelle (the operator of five national laboratories). The ONAMI board is chaired by a general partner of the state's leading venture capital firm and ONAMI has relationships with many others in the investment community. ONAMI's sponsored research includes research collaborations with HP, FEI, LSI, Nantero, Xerox, many smaller companies, and Intel. In several cases, we are able to work with industry research and production facilities that are far superior to anything most universities typically acquire. ONAMI also has a physical joint venture with PNNL/Battelle, which is a unique asset for not only performing cutting edge research, but translating that research into new products, new companies, and high-wage jobs.

At Oregon State University, I also want to mention other efforts that keep the university connected to industry. In our College of Engineering, we have a very successful internship program, the Multiple Engineering Cooperative Program (MECOP). This internship experience is so sophisticated it bears little resemblance to the ordinary internships that are increasingly common in higher education. MECOP is, and has been since its inception more than 20 years ago, self-supporting. Dues are paid by participating businesses and industry to support the staff needed to develop, monitor and fine-tune the program. The program is built on a high order of industry interaction with the university and its students; and it is continually improved as the University adjusts its curriculum on recommendations made by the industry partners. Participating industries include Freightliner, Boeing, Sun Microsytems, Tektronix and many, many others. Additionally, as at other institutions, OSU faculty are engaged in industry funded R&D, some researchers utilize

their sabbatical leave to gain private industry experience and others take leaves of absence to help start up new companies.

While our ties to private industry are strong, there are existing barriers to collaboration. The first is industry's need to own the intellectual property rights on research they pay for, which can be in direct conflict with faculty and student needs to publish their work, as well as, in some instances, public information laws. An additional barrier is the proprietary nature of private business strategic plans and their internal efforts to achieve them. It is often difficult for academic researchers to know if their work is relevant to industry needs when industry is trying to protect their product development efforts to ensure they are developing unique and competitive products for the marketplace.

Academic and research funding traditions and cultures have traditionally not rewarded (through promotion, tenure, peer reputation) researchers for working in teams, performing industrially relevant research, patenting their inventions, or commercialization. In addition, unpredictable funding processes in both industry and academia also present challenges. Industry also is subject to frequent organizational restructuring involving staff turnover and reassignment.

The lack of research funding for joint industry/university research is a critical barrier and has slowed down several promising opportunities. While larger businesses typically have some kind of R&D budget, this is not the case for smaller, emerging businesses. Generally there is a lack of university funding for what the military calls "6.2" research, research that seeks the application of basic science. The National Science Foundation (NSF) funds nearly exclusively basic science and does not typically fund development. The Defense Advanced Research Projects Agency (DARPA) is the best source for university 6.2 funding, but this often is for highly specialized devices with military applications and without a strong commercial market. ONAMI researchers have expressed a need for a source of funding that could be seen as "a DARPA" for commercial nanotechnology.

- **How does the State of Oregon provide support to OSU and ONAMI for nanotechnology and other high-technology activities? How does this complement funding from the Federal Government and the private sector? What, if any, gaps remain?**

With unprecedented focus and consensus, Oregon has chosen to focus on Nanoscience and Microtechnologies as the state's first "signature research center", based on a clear finding that this represented the greatest overlap of (1) existing research excellence, (2) future market opportunity, and (3) Oregon's existing industrial strengths. In 2003, the State committed $21 million to ONAMI, and the Governor included $7 million in the proposed state budget for 2005–6. In addition, there is a dedicated State of Oregon Innovation Economy Officer, a proposed statutory Oregon Innovation Council, and state-assisted mechanisms to increase the supply of venture capital by almost $140M, of which over $30M will be pre-seed and seed stage. The state's role is to assist the research institutions in increasing their capacity for competitive sponsored research and to assist entrepreneurs in commercializing new technology.

Industry support of ONAMI's operation since its inception has totaled approximately $10 million in equipment, facilities use commitments, R&D, and gifts. Other research awards have totaled approximately $25 million, including federal awards from the Department of Defense and NSF, as well as foundation awards. Oregon State University's commitment thus far, outside of the specified state appropriations for ONAMI, is estimated to be approximately $3 million.

Again, the gap between State, federal and private support is in support for investigations in technologies that are beyond the basic research, but not quite ready to be tested for commercialization. Smaller businesses often simply do not have research budgets to support these needs, and government funding for this stage of inquiry is not widely available.

- **What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?**

During the December 2004 Oregon Leadership Summit Steve Grant ,Vice President for the Technology & Manufacturing Group at Intel Corporation reported that, "Over the last four years, Intel has hired 441 PhD's in engineering and computer science in Oregon. Only seven came from the Oregon University System. [Intel] hired 347 Master's degree engineers and only 11 percent came from Oregon schools. At the Bachelor degree level [they] did better, with 21 percent." Oregon is not pro-

ducing enough highly skilled quality engineers to meet our hiring needs, especially at the graduate levels. However, this is not just the case in Oregon, it is a problem nationwide.

Increased barriers to American colleges and universities for foreign students, as well as greatly enhanced opportunities for them at home, and a lack of progress in filling the pipeline with qualified American students are trends in direct opposition to an increased need for workers with advanced degrees in physical sciences and engineering. Without a trained workforce, the United States will find it hard to remain a leader in nanotechnology. Further, intense global competition has reduced industry's investment in scientific research, while the Federal Government investment in research that will lead to technology-based economic development has stagnated. This is a confluence of unfavorable trends.

I know you have heard this message repeatedly, but federal funds for physical science and engineering are a part of what is needed to address the work force issue. In the end, faculty and graduate students go where the money is and funding for nanotechnology research is critical for producing the graduate level workforce that nanotechnology-based industry needs. Since World War II, the Federal Government has supported training grants and research assistantships hand-in-hand with support for basic research. The combination of study and training is a successful avenue to train a highly educated workforce.

We also need a greater emphasis on curriculum development at all levels with serious research on what academic skills are needed for the emerging technologies, best practices in science and engineering education need to be identified and disseminated throughout the academic community.

What is also critical is inspiring young students, in elementary school, high school, and as undergraduates to see themselves as scientists and to be exposed to exciting new and multi-disciplinary trends. We need more students to find scientific concepts practical and approachable and we need to inspire them to consider careers in science. At Oregon State University, we are host to numerous outreach programs that try to get the attention of future scientists and engineers. Many of these programs, too, are federally funded, such as the NSF GK–12 graduate fellowship program, and the NASA Space Grant program, and I encourage you to continue to invest in these activities and to work toward ensuring that they are administered in a way that ensures their effectiveness. I also think that there should be ways to encourage novel curricular changes.

- **How can Federal and State governments, industry, and academia best cooperate to facilitate advances in nanotechnology?**

It is generally recognized that university-based research is a long-term investment in the future. The Federal Government's support for basic research contributes to the discoveries and innovation that underpins the future technologies and knowledge that contribute to the well-being of our nation. However, as our scientists get involved in areas of research, such as nanotechnology, where there are demands for near-term delivery, many challenges emerge.

In order to facilitate advances in these areas, one possible solution is to establish federal funding sources that set clear objectives related to translation of technology and economic development, put in place metrics to measure progress against these goals, and hold recipients of funding accountable for achieving outcomes. While this is not an appropriate direction to take with basic research, there are ways to designate a certain percentage of publicly funded research for multi-disciplinary teams focused on big and emerging fields with a potential for translation and commercialization. An example of this is the NIH Roadmap Initiative and the National Cancer Institute (NCI) National Cooperative Drug Discovery Programs (NCDDGs).

As I noted earlier, three words describe ONAMI: innovation, collaboration, and commercialization. If Federal and State governments, industry, and academia can all keep these in mind as they examine avenues to advance nanotechnology research and development, it is the public that will benefit from individuals who can take advantage of such devices as compact, portable, home kidney dialysis devices to communities which experience economic prosperity with the establishment of new nanotechnology businesses and industry.

In conclusion, I wish to thank you for this opportunity to address you today. Nanotechnology is an exciting new area which will have tremendous impact across multiple fields of science and throughout many aspects of our lives. We are excited that in Oregon we have been able to develop a vision for significant partnerships such as ONAMI and that private, State, federal and university investments have made the vision a reality.

BIOGRAPHY FOR JOHN M. CASSADY

John M. Cassady received a B.A degree from DePauw University in 1960 with a major in chemistry; he obtained his M.S. degree in 1962 and his Ph.D. degree in 1964 from Western Reserve University with a major in Organic Chemistry. Dr. Cassady was an NIH postdoctoral fellow from 1965–1966 at the University of Wisconsin where he worked under the direction of Dr. Morris Kupchan on the isolation and structural elucidation of tumor inhibitors from plants. In 1966, he joined the faculty of the School of Pharmacy, Purdue University as Assistant Professor in the Department of Medicinal Chemistry and Pharmacognosy. He was promoted to Associate Professor in 1970 and Professor in 1974. He was appointed Associate Head of the Department of Medicinal Chemistry and Pharmacognosy in 1976 and became Head of the Department in January 1980. In 1987, Dr. Cassady was appointed as the Glenn L. Jenkins Distinguished Professor of Medicinal Chemistry and Pharmacognosy at Ohio State University College of Pharmacy. On July 1, 2003 he returned to the faculty after more than 15 years as Dean. Dr. Cassady was appointed as Vice President for Research at Oregon State University, March 2005.

Dr. Cassady holds membership in the American Chemical Society, American Society of Pharmacognosy (ASP), Academy of Pharmaceutical Sciences, British Chemical Society, AACR, ASHP, AAAS, Sigma Xi, Rho Chi, and the AACP. He has served on the nominating and publicity committees for the ASP, was scientific program chairman for the 1976 annual meeting of the Society, was elected to the Executive Committee (1978–1981) and President (1993–1994) and is chair of the ASP Foundation Board (1995–present). He has served as a consultant to the National Institutes of Health and was a member of the Bioorganic and Natural Products Study Section from 1980–1984. He has served on the Editorial Advisory Board of the *Journal of Natural Products* and the *Journal of Medicinal Chemistry*. Dr. Cassady has served on the publicity, scientific program and awards committees for the Medicinal Chemistry Division of the American Chemical Society. He was appointed a member of the Long-Range Planning Committee of the Medicinal Chemistry Division from 1983–1986 and in 1987 he was elected Councilor for the Medicinal Chemistry Division. He was appointed to the National Association of Chain Drug Stores (NACDS) National Advisory Council from 1997–2002. He was a member of the AACP National Commission on Graduate Education (1996–1998), Chair of the AACP Institutional Research Advisory Committee (1997–1998), and a member of the Ad Hoc Committee on Academic Budgeting and Accountability (1997–1998). He was elected AAAS Chair-elect for the Section of Pharmaceutical Sciences in 1997 and served as Chair from 1999–2000. He served on the ASHP Commission on Goals in 2001 and 2002. He currently serves on the Corporate Advisory Board of Pacific Northwest National Laboratories (PNNL).

Dr. Cassady's research interests involved the discovery and design of anticancer drugs from natural products and nutraceuticals, specifically, the isolation, structural elucidation, and chemical studies of chemopreventive and antitumor agents from higher plants and the synthesis of potential antitumor agents. Other areas of research interest involved the design of enzyme inhibitors, including protein tyrosine kinases, synthesis of selective dopamine agonists as potential antipsychotic agents, anti-malarial and anti-Parkinson's agents from natural products. His research resulted in the publication of more than 150 manuscripts and 150 abstracts and over $12,000,000 in research support from the NIH and other funding agencies. Dr. Cassady has developed strategic alliances between academic and corporate sectors. He led a strategic alliance with Pharmacia, served on the Corporate Advisory Board of Yuhai Phytochemicals, China, Dean's Advisory Board for Merck-Medco and as a consultant for Gaia Botanicals, Leadscope, Milkhaus and SSCI.

Dr. Cassady was elected to membership in the Royal Society of Chemistry and American Association for Advances in Cancer Research, was elected a Fellow of the Academy of Pharmaceutical Sciences in 1979, a Fellow of the American Association of Pharmaceutical Sciences in 1987 and a Fellow of the AAAS in 1990. Dr. Cassady received the Purdue University Cancer Research Award in 1981 and the Gisvold Lecture Award from the University of Minnesota in 1986. In June 1989, he was awarded the D.Sc. (Hon.) by DePauw University. He received the Research Achievement award in Natural Products Chemistry from the American Pharmaceutical Association in 1990. In 1991, he was appointed Honorary Professor to the Institute of Medicinal Plant Development by the Chinese Academy of Medical Sciences.

OSU
Oregon State University

John M. Cassady, Vice President for Research
Oregon State University, 312A Kerr Administration Building, Corvallis, Oregon 97331-2140
Phone 541-737-0662 | Fax 541-737-3093 | oregonstate.edu/research | John.Cassady@oregonstate.edu

May 10, 2005

The Honorable Bob Inglis
Chairman, Research Subcommittee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Inglis:

Thank you for the invitation to testify before the Research Subcommittee of the Committee on Science of the U.S. House of Representatives on May 18th for the hearing entitled "***The National Nanotechnology Initiative: Review and Outlook.***" In accordance with the Rules Governing Testimony, I want to confirm that I received no federal funding directly supporting the subject matter on which I will testify, in the current fiscal year or either of the two proceeding fiscal years.

Sincerely,

John M. Cassady

John M. Cassady, Ph.D.
Vice President for Research

JMC:nrn

Chairman INGLIS. Thank you, Dr. Cassady.
Mr. Fancher.

STATEMENT OF MR. MICHAEL FANCHER, DIRECTOR OF ECONOMIC OUTREACH, ASSOCIATE PROFESSOR OF NANOECONOMICS, ALBANY NANOTECH

Mr. FANCHER. Thank you, Mr. Chairman and Members of the House Research Subcommittee on the Committee on Science. I am appearing here today to provide our perspective on what we believe is a new model for technology, business, and education that creates what I would call a naturally occurring multiplier, or as PCAST refers to it as the innovation cluster with academia, governmental agencies, and industry each contributing and benefiting in their own way.

It is important for the Science Committee to understand that nanotechnology is emerging from the discovery phase and is now entering the commercialization stage and that the NNI must evolve and expand its funding priorities to address the daunting tech-

nology, business, and economic challenges confronting the Nation's high-tech industries.

As the promise of nanotechnology provides game-changing opportunities in a variety of applications as being better defined, as we heard from Scott Donnelly, it is becoming increasingly apparent that the cost to commercialize nanotechnology is rising exponentially.

Chairman INGLIS. Mr. Fancher, excuse me just a second.

Mr. FANCHER. Yes.

Chairman INGLIS. Do you want some slides up?

Mr. FANCHER. Yes, I am. This is just my intro.

Chairman INGLIS. Oh, okay.

Mr. FANCHER. Companies are seeking new models to collaborate.

What I would like to do is just provide a few slides to describe what that model is, and so please bear with me.

[Slide.]

I think it is helpful to understand that—and we have heard already that Oregon is taking the—New York—the state has gotten involved in this, and New York State has, I think, done it in a way that I think can be replicated around the country. And when you look at the strategy New York State is focused on, it has been four key drivers: selecting an overarching discipline, such as nanotechnology, investing in state-of-the-art infrastructure, focusing on world-class, hands-on education and training, not just Ph.D. and Masters in Engineering, but the whole supply chain, and then, of course, leverage public-private partnerships.

I would like to just spend a slide on each to give you an example.

[Slide.]

Well, nanochips. We have already heard about it. Nanochips are enabling defense, bio-health, sensors, aerospace, pervasive tether-free computing, communications, energy, and of course, automotive industry. I think the key element here, though, is the nanochip industry is probably the first industry that has begun integrating nanotechnology into a high-yield, low-cost production process mode. That means they are breaking the ground for other industries to adapt that technology, that process technology, to a variety of applications.

[Slide.]

A key driver, too, for New York State has been investment in state-of-the-art infrastructure. This is the Albany NanoTech complex. It will be at about $3 billion in assets by the end of 2006 in addition to the facilities that you see there. We have around 750,000 square feet of cutting-edge facilities with 85,000 square feet of clean rooms for what is known as "300-millimeter wafer process technology." That is important because 300-millimeter is the state-of-the-art of technology used by the computer chip industry. And it will be the platform on which nanotechnology is integrated for a variety of those applications that I already described.

Our partners include Sematech, IBM, AMD, Micron, Tokyo Electron, General Electric, and ASML. We have 200 researchers at Albany NanoTech in the college and 300 industry scientists on site, and by the end of 2007, we will have around 1,600 people in the complex.

I would like to spend just two slides on workforce, because I think that is a particularly important challenge.

[Slide.]

And with that we have established the world's first college of nanoscale science and engineering. We have constellations in nanoscience, nano-engineering, nano-biotechnology, and nano-economics, of which I am Associate Professor in that school.

I think when you look at the challenge for the workforce, what you are looking at, and I am quoting the National Science Foundation, is that the United States will need two million nanotech-savvy workers by the year 2014. That is a daunting challenge when you consider that China is producing 250,000 engineers and scientists per year while we are producing 56,000 engineers and scientists, and I take that number from the American Electronics Association.

When you look at the breakdown of that two million, 20 percent will be scientists, and 80 percent will be the engineers, technicians, operators, business leaders, etc. So that means we need to start focusing on children 10 to 17 years old right now if we are going to make that objective.

I would like to give a case in point on what Albany NanoTech has been doing in the College of Nanoscale Science and Engineering to meet those workforce needs.

Well, as I have said, we have established the world's first college to break the walls down between the sciences so that everyone is talking common language between biology, computational science, physics, and chemistry. We have established partnerships with our community colleges, supporting the semiconductor manufacturing technology training program for the operators of the tools. We have high school and undergraduates doing internships in the program. And we also host the semiconductor equipment materials international workforce development institute, what we call a "chip camp." It is a four-day exposure for your vocational students. And then finally, we have established a $6 million center for the construction trades.

Again, I think what is important to understand is that atomic-scale manufacturing, if pushing all levels in the workforce to rise to new levels of expertise and training right down to the construction of the building to hooking up the equipment is all now very critical to the success of the overall commercialization.

The third driver for New York State has been establishing the Center of Excellence in Nano-electronics by Governor Pataki back in 2001. This has been—and I am just doing this as a timeline, but it has been critical to provide the infrastructure and partnerships with industry, with the SAI, with the focus center, IBM, the anchor tenant, and the Center of Excellence with $150 million. We have a Sematech North program, Tokyo Electron R&D center, the first established outside of Japan is embedded in our facilities. Our complex was completed about a year ago. Albany NanoTech was formed. We have established the first college. We recently announced the $400 million research center with ASML, one of the world leaders in lithography equipment. And then finally, we are closing on what we call the Center for Semiconductor Research, a partnership with Applied Materials, which is about $450 million.

So I would like to take that focus of where we are, and now let us go take it to the global marketplace.

I think it is important for you to understand that our competition is very steep, and it is global, and that what is happening in the nanochip world is global alliances. And when you look at what is going on in Albany, you are seeing a partnership that initially started with AMD, Sematech, and IBM and has now grown to Sony, Toshiba, and Chartered Semiconductor. Our competition is in Belgium. It is IMEK. It includes SD Phillips, and a few other companies, TSMC, and Motorola, and then, of course, Japan.

The global R&D competition drives the industry clustering effect that PCAST mentioned. And for New York State, we have already achieved $8 billion of investment just since 2002. I think two——

Chairman INGLIS. Mr. Fancher.

Mr. FANCHER. Yes.

Chairman INGLIS. Hold on just a second.

Mr. FANCHER. Okay.

Chairman INGLIS. We are expecting votes at 11:15, so we probably need to move a little quickly.

Mr. FANCHER. Okay.

[The prepared statement of Mr. Fancher follows:]

PREPARED STATEMENT OF MICHAEL FANCHER

A Successful New Paradigm for Innovation and Education

University based, co-located with some of the biggest names in industrial innovation, and committed to building a thriving, educated and globally-competitive workforce, Albany NanoTech is a $3 billion enterprise dedicated to creating partnerships for leading edge nanotechnology innovations. Through its unique, vertically-integrated model that includes the world's first College for Nanoscale Sciences and Engineering at the University at Albany—State University of New York, Albany NanoTech's partnerships with business, government and academia have created the world's premier powerhouse for research, development, technology deployment, and education resource supporting accelerated nanotechnology commercialization.

Albany NanoTech is the umbrella under which the CNSE and the five Centers operate; namely, the Center of Excellence in Nanoelectronics, Center for Advanced Technology in Nanomaterials and Nanoelectronics, Interconnect Focus Center, Nanoscale Metrology and Imaging Center, and the Energy and Environmental Technology Applications Center. The CNSE and the five centers are all located at Albany NanoTech and have access to its facilities, but the nature of our model—through which there are no divisions between disciplines, or between academia and industry—means that there is great cooperation and cross-pollination among the various centers and between CNSE faculty and industrial partners. Faculty are involved in all of the centers and in some cases, the centers cooperate closely with one another to advance the science. Nobody is working in silos, and that is part of the reason why we have been able to get so much accomplished.

Partnerships

How does Albany NanoTech interface with the private sector?

Albany NanoTech seeks to leverage resources in partnership with business, government, and academia to create jobs and economic growth for nanoelectronics-related industries. Governor George E. Pataki created a Center of Excellence in Nanoelectronics at Albany NanoTech's facilities in 2001 and since then has worked very closely on building relationships with leading industrial players in nanoelectronics like IBM, ASML, Tokyo Electron, and International Sematech. Since 2001, we have attracted over $1 billion in direct private investment and now have over 100 industrial partners many of whom are on-site, which represent companies of all sizes that share a commitment to nanotechnology innovation.

Boasting over 100 partnerships with universities, federal labs, and industry such as RPI, Stony Brook University, Argonne National Laboratory, DARPA, NASA, Gen-

eral Electric, Honeywell, and IBM, to name a few, Albany NanoTech strives to help companies overcome technical, market, and business development barriers through technology incubation, pilot prototyping, and testbed integration support leading to targeted deployment of nanotechnology-based products.

Albany NanoTech's partnerships encompass multi-year research programs with IBM, ASML, Tokyo Electron, Applied Materials, Infineon and Micron as well as sponsored research collaborations with national defense agencies, such as the Naval Research Laboratory and DARPA as well as start-up companies, such as Daystar Systems and Crystal IS. Small, medium and large corporate and university partners have access to state-of-the-art laboratories, shared user facilities, supercomputing capabilities, and an array of research and development centers serving the short-, medium-, and long-term nanotechnology development needs while training the workforce for the 21st century. Partners are able to collaborate formally and informally, establish strategic alliances, or form joint ventures and consortia within a technically aggressive and financially competitive environment.

The CNSE & Centers

What is the workforce outlook for nanotechnology, and how can the Federal Government and universities help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

According to National Science Foundation, the U.S. will need approximately two million nanotech savvy workers by 2014. Approximately 20 percent of these workers are expected to be scientists, 80 percent must be highly-skilled engineers, technicians, business leaders, economists, etc., and that means children between the ages of 10 and 17 need to be educated NOW about the field that will define their job market as adults.

The location of the College in the Albany NanoTech complex provides students with a unique public-private education through research partnerships that are not available at any other college or university. This partnership allows maximum leveraging of synergistic resources to create a comprehensive, fully integrated powerhouse for the attraction and retention of highly qualified students to careers in the various disciplines of nanotechnology, from theoretical principles to experimental demonstrations and practical applications.

As the first of its kind, the College provides a comprehensive education of the highest quality enabling the discovery and dissemination of fundamental knowledge concepts and new frontier scientific principles in the emerging interdisciplinary fields of nanotechnology, from nanosciences and nanoengineering to nanoeconomics. The College offers Ph.D. and M.S. degrees in the science and engineering tracks pertaining to the nanoelectronics, opto-electronic, optical, nano/micro-electro-mechanical, nano/micro-opto-electro-mechanical, energy, and nanobiological fields with curriculum integrating the fundamental science principles of physics, chemistry, computational science and biology with the cross cutting fields of nanosciences, nanoengineering and nanotechnology.

In addition, the College supports hands-on workforce training by providing access to state-of-the-art facilities, training the entire spectrum of technicians, operators and technical trades through partnerships with community colleges, high schools and leading industry players. CNSE has established partnerships with several community colleges providing the hands-on workforce component to their associate degree education necessary to operate nanotechnology equipment. The CNSE works with local undergraduate colleges and high schools by sponsoring year round and summer internships for students and by hosting in partnership with the Semiconductor Equipment and Materials International (SEMI) four day "chip camps" targeting high school vocational students to encourage then to consider carriers in nanotechnology through hands-on curriculum. Finally, Albany NanoTech participates in a $6 million workforce training partnership for nanotech infrastructure construction trades in partnership with M+W Zander, one of the world leaders in nanotechnology facility design and construction, the Watervliet Arsenal Partnership and New York State.

Research & Facilities

The research performed at Albany NanoTech is broadly focused on all aspects of the emerging nanosciences including: nanoelectronics and microelectronics, Nano/Microsystems including MEMS, nanometrology, nanophotonics and opto-electronics, analytical sciences and process control, nanopower, and advanced computer modeling for nanosystems and processes.

To assist in accomplishing these prominent research goals, Albany NanoTech consists of over 500,000 square feet of on-site office, laboratory, and cleanroom incuba-

tion facilities. The complex includes the only 200mm/300mm wafer facilities in the academic world that encompasses nanoelectronics; system-on-a-chip technologies; biochips; opto-electronics and photonics devices; closed-loop sensors for monitoring, detection, and protection; and ultra-high-speed communication components.

Albany NanoTech has literally hundreds of tools, ranging from STMs and supercomputers to the ASML TWINSCAN AT:1500i scanner, the world's first 300mm wafer immersion lithography tool. Our tool arsenal is one of our best recruiting tools, since many of our scientists can do everything they need to advance their research right here.

NanoFab 300 South, which opened in January 2003, is a 138,000-square-foot technology acceleration facility that provides for business incubation, classrooms for the CNSE, workforce training, offices for Albany NanoTech, and large and small industrial sponsors and partners including IBM, TEL, Honeywell, and SEMATECH North. The facility also includes 16,000 square feet of cleanroom to support the SEMATECH North, IBM, and other next-generation nanotechnology research activities.

Scheduled to be completed by the end of 2005, NanoFab 300-North features a 35,000 square foot Class 1-capable 300mm wafer R&D cleanroom, pilot prototype, incubation, and workplace training facility that will house a full nanoelectronics process line. The 500,000+ square-foot complex includes over 65,000 square feet of cleanroom space supporting the nanoelectronics-related industries. Albany NanoTech not only has the site where the world's first 300mm wafer immersion lithography tool was installed in August 2004, enabling partners like IBM to get a jump on this technology but Sematech has also announced that it is conducting the bulk of its research in extreme ultraviolet (EUV) lithography at its laboratories located at Albany NanoTech. The fact that two leading organizations in nanotechnology research—IBM and Sematech—have both announced major lithography research milestones in the past year and both of these took place at Albany NanoTech demonstrates the effectiveness of the model.

The NY "Nano" State

How does the State of New York provide support to Albany NanoTech and the College of Nanoscale Science and Engineering at UAlbany–SUNY? How does this complement funding from the Federal Government and the private sector? What, if any, gaps remain?

New York and its industrial partners committed over $1.4 billion to establish five Centers of Excellence throughout the State in nanoelectronics, photonics, bioinformatics, information technology, and environmental systems. Each Center of Excellence acts as a bridge between scientific discovery and commercialization by supporting pilot-prototyping development, workforce training and economic outreach. Combined, these distributed technology deployment centers represent a comprehensive nanotechnology commercialization effort reflecting regional strengths.

Government support encouraging private and public investment in nanotechnology is a key to industry success and future economic growth. New York's tremendous support of nanotechnology development has caused industry leaders such as IBM, General Electric, and Corning to expand their research and development activities within the state. New York State's support for joint technology research, development and deployment in the form of state-of-the-art facilities and capabilities has played an important role in lowering the risk and cost for companies to accelerate the commercialization of nanotechnology.

New York State already shows signs of being a 'Nano Hub' and, in particular, the capital region is becoming the world's first 'Nanopolis.' Since 2002, two of the world's most influential tool suppliers, Tokyo Electron and ASML, have chosen to open up their first cutting-edge R&D laboratories outside their home countries at Albany NanoTech. Smaller high-tech startups like Starfire Technologies and Evident Technologies that were incubated at Albany are growing and attracting venture capital funding. Finally, we are finding companies are actually moving to Albany from other parts of the world.

The Future & Recommendations

Albany NanoTech's overarching goal is to become the Bell Labs of the new millennium—bringing the best minds together, whether they are in industry, government or academia, to work on leading-edge technologies that can revolutionize our lives in the coming decades. In the immediate term, this means building partnerships and creating a paradigm that practically compels companies that value leading-edge nanotechnology research to establish partnerships at Albany NanoTech if they want to remain competitive. In the long-term, it means re-inventing and drastically speeding how innovation is brought to market.

The College's goals are to completely redefine how scientists are educated by tearing down the traditional disciplinary silos in which they operate and by tearing down the barriers between the research institutions, community colleges, high schools, vocational schools and even the trades. We are confident that subjects like biology, chemistry, physics and medicine will become increasingly irrelevant in the coming decades as science merges around the development of tool sets and methodologies. In the immediate term, we want CNSE to be part of this redefinition of research and pedagogy. In the long term, we aspire to create a world-class academic center on par with—but not a clone of—the world's greatest research universities.

Atomic-scale manufacturing requires a closer coupling between research, development and manufacturing. A new generation of institutions executing dynamic cross-industry, cross disciplinary models are emerging, such as Albany NanoTech, that are responding to the unique challenges and opportunities created by nanotechnology. These institutions are establishing a new paradigm for state-of-the-art research, education and technology deployment that offers the Federal Government a highly leveraged return on its investment in projects, programs and centers.

Federal funding must recognize the emergence of new university-based technology, educational, and business models that concurrently support long-term research, medium-term development and short-term manufacturing. Federal funding should reward universities and state governments who successfully pursue new paradigms for innovation and education by encouraging joint investments in shared-use infrastructure by industry. Federal investments in shared-use infrastructure supporting the entire continuum of nanotechnology research, development and manufacturing must be a strategic priority supporting. New business and technology models such as Albany NanoTech's is critical for U.S. industry to convert nanotechnology discovery into commercial opportunities supporting national industrial competitiveness and defense and security priorities.

Shared investment and collaboration by industry, academia and government not only improves the probability of success, leading to economic growth for both small and large companies, but also provides the critical infrastructure necessary to support educational programs for the entire spectrum of workers to effectively compete in the 21st Century. Significant and consistent support for the operations of this university-based shared-use infrastructure by the Federal Government is critical for supporting the growth of small, medium and large companies, training the entire spectrum of nanotech savvy workers with hands-on educational programs, and achieving the grand challenges set forth under the National Nanotechnology Initiative (NNI) which are critical for national defense, public health and economic security. More specifically, continued support for the NNI should be a priority while recognizing that current programs neither effectively address nor accommodate less traditional models, and as such, requires a new category of funding to support "Successful New Paradigms for Innovation and Education."

For more information about Albany NanoTech, its mission and its programs, visit our website at www.albanynanotech.org or contact Michael Fancher, Director of Economic Outreach at mfancher@uamail.albany.edu.

Nanotech Briefs

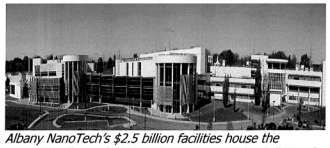
Engineering Breakthroughs in Nanotechnology & MEMS

Profile on Albany NanoTech

Reprinted from March 2005 Issue

Albany NanoTech (Albany, NY), co-located with the College of Nanoscale Science and Engineering (CNSE) at the University at Albany (SUNY) is a $2.5-billion global research, development, technology deployment, and education resource supporting accelerated high-technology commercialization. According to Professor Alain E. Kaloyeros, Ph.D., President of Albany NanoTech, "The real visionary behind Albany NanoTech was Governor George Pataki, who proposed creating a Center of Excellence in Nanoelectronics at our facilities in 2001. Prior to that, Albany NanoTech had success in building scientific partnerships through the Interconnect Focus Center with Stanford University, Harvard University, Massachusetts Institute of Technology (MIT), and Rensselaer Polytechnic Institute (RPI)."

Today, Albany NanoTech seeks to leverage resources in partnership with business, government, and academia to create jobs and economic growth for nanoelectronics-related industries. "The Governor worked very closely on building relationships with leading industrial players in nanoelectronics like IBM, ASML, Tokyo Electron, and International Sematech. Since then, we've attracted over $1 billion in direct private investment and now have over 100 industrial partners many of whom are on site, which represent companies of all sizes that share a commitment to nanotechnology innovation," said Kaloyeros.



Albany NanoTech's $2.5 billion facilities house the research efforts of industrial partners and the College of Nanoscale Science and Engineering.

The NY "Nano" State

New York and its industrial partners committed over $1.4 billion to establish five Centers of Excellence throughout the State in nanoelectronics, photonics, bioinformatics, information technology, and environmental systems. Combined, these distributed technology deployment centers represent a comprehensive nanotechnology commercialization effort reflecting regional strengths.

Government support encouraging private and public investment in nanotechnology is a key to industry success and future economic growth. New York's tremendous support of nanotechnology development has caused industry leaders such as IBM, General Electric, and Corning to expand their research and development activities within the state. In essence, New York is on the right path towards leading the global nanotechnology revolution.

"New York State already shows signs of being a 'Nano Hub' and, in particular, the capital region is becoming the world's first 'Nanopolis.' Since 2002, two of the world's most influential tool suppliers, Tokyo Electron and ASML, have chosen to open up their first cutting-edge R&D laboratories outside their home countries at Albany NanoTech," said Kaloyeros. "Smaller high-tech startups like Starfire Technologies and Evident Technologies that were incubated at Albany are growing and attracting VC funding. Finally, we're finding companies are actually moving to Albany from other parts of the world. Recently, EV Group moved its northeastern headquarters from Providence, RI to Albany – primarily due to the resources we have at Albany NanoTech," he said.

The CNSE & Centers

Albany NanoTech is the umbrella under which the College of Nanoscale Science and Engineering (CNSE) and the five Centers operate; namely, the Center of Excellence in Nanoelectronics, Center for Advanced Technology in Nanomaterials and Nanoelectronics, Interconnect Focus Center, Nanoscale Metrology and Imaging Center, and the Energy and Environmental Technology Applications Center.

"The CNSE and the five centers are all located at Albany NanoTech and have access to its facilities, but the nature of our model – through which there are no divisions between disciplines, or between academia and industry – means that there is great cooperation and cross-pollination among the various center and between CNSE faculty and industrial partners," said Professor James Castracane, director of technology at Albany NanoTech. "Faculty are involved in all of the centers and in some cases, the centers cooperate closely with one another to advance the science. For example, the Nanoscale Metrology and Imaging Center, which essentially measures and characterizes nanomaterials, is an integral part of all the research at Albany NanoTech. Nobody is working in silos, and that's part of the reason why we've been able to get so much accomplished."

Officially launched in September 2004, the CNSE —the first college devoted to the study of nanoscale scientific concepts – enables the discovery and dissemination of fundamental knowledge and new frontier scientific principles in the interdisciplinary fields of nanotechnology. The CNSE offers the degrees of Doctor of Philosophy (Ph.D.) and Masters of Science (M.S.) in selected science and science and engineering tracks pertaining to the nanoelectronic, optoelectronic, optical, nano/micro-electro-mechanical, energy, and nanobiological fields. The school awarded the world's first PH.D. degrees in nanoscience to Drs. Spyridon Skordas and Wanxue Zeng in December 2004.

"Because we are the only college in the world dedicated exclusively to nanoscale scientific concepts, we've been able to focus on a wide range of areas within what has come to be known as nanoscience, from optoelectronics to environmental sensor technologies to spintronics to nanobiomedical technologies. Over the course of the next couple of

years, we intend to recruit over 30 new faculty members, who will help us to continue to enrich our areas of strength," said Kaloyeros.

Over 30 CNSE faculty members and instructors currently advise and supervise more than 75 Ph.D. and M.S. level students within a dozen electronic classrooms at the complex. CNSE offers over 50 courses within its "constellations" in nanoscience, nanoengineering, and nanoeconomics, with plans to further expand its curricula in nanobiotechnology.

Research & Facilities

The research performed at Albany NanoTech is broadly focused on all aspects of the emerging nanosciences including: nanoelectronics and microelectronics, Nano/Microsystems including MEMS, nanometrology, nanophotonics and optoelectronics, analytical sciences and process control, nanopower, and advanced computer modeling for nanosystems and processes.

Researchers in the CNSE spintronics laboratory.

To assist in accomplishing these prominent research goals, Albany NanoTech consists of over 500,000 square feet of on-site office, laboratory, and cleanroom incubation facilities. The complex includes the only 200-mm/300-mm wafer facilities in the academic world that encompasses nanoelectronics; system-on-a-chip technologies; biochips; optoelectronics and photonics devices; closed-loop sensors for monitoring, detection, and protection; and ultra-high-speed communication components.

"Albany NanoTech [has] literally hundreds of tools, ranging from STMs and supercomputers to the ASML TWINSCAN AT:1500i scanner, the world's first 300 mm wafer immersion lithography tool. Our tool arsenal is one of our best recruiting tools, since many of our scientists can do everything they need to advance their research right here," said Castracane.

NanoFab 300 South, which opened in January 2003, is a 138,000-square-foot technology acceleration facility that provides for business incubation, classrooms for the CNSE, workforce training, offices for Albany NanoTech, and large and small industrial sponsors and partners including IBM, TEL, Honeywell, and SEMATECH North. The facility also includes 16,000 square feet of cleanroom to support the SEMATECH North, IBM, and other next-generation nanotechnology research activities.

Scheduled to be completed by mid-2005, NanoFab 300-North features a 35,000 square foot Class 1-capable 300-mm wafer R&D cleanroom, pilot prototype, incubation, and workplace training facility that will house a full nanoelectronics process line. The 500,000+ square-foot complex includes over 65,000 square feet of cleanroom space supporting the nanoelectronics-related industries.

Castracane said, "Albany NanoTech not only has the site where the world's first 300 mm wafer immersion lithography tool was installed in August 2004, enabling partners like IBM to get a jump on this technology but Sematech has also announced that it is conducting the bulk of its research in extreme ultraviolet (EUV) lithography at its laboratories located at Albany NanoTech. The fact that two leading organizations in nanotechnology research – IBM and Sematech – have both announced major lithography research milestones in the past year and both of these took place at Albany NanoTech is an enormous source of pride for me."

Partnerships

Boasting over 100 partnerships with universities, federal labs, and industry such as RPI, Stony Brook University, Argonne National Laboratory, DARPA, NASA, General Electric, Honeywell, and IBM, to name a few, Albany NanoTech strives to help companies overcome technical, market, and business development barriers through technology incubation, pilot prototyping, and test-bed integration support leading to targeted deployment of nanotechnology-based products Small, medium and large industrial partners can access Albany NanoTech's state-of-the-art laboratories, supercomputer center, shared-user facilities, and a range of scientific centers serving their long-and short-term technology development needs.

The Future

When asked about the future goals of Albany NanoTech, Kaloyeros responded, "Albany NanoTech's overarching goal is to become the Bell Labs of the new millennium – bringing the best minds together, whether they are in industry or academia, to work on leading-edge technologies that can revolutionize our lives in the coming decades. In the immediate term, this means building partnerships and creating a paradigm that practically compels companies that value leading-edge nanotechnology research to establish a presence at Albany NanoTech if they want to remain competitive. In the long term, it means reinventing and drastically speeding how innovation is brought to market."

Kaloyeros added, "For CNSE, our goals are equally lofty. We seek to completely redefine how scientists are educated by tearing down the traditional disciplinary silos in which they operate. We're confident that subjects like biology, chemistry, physics and medicine will become increasingly irrelevant in the coming decades as science merges around the development of tools sets and methodologies. IN the immediate term, we want CNSE to be part of this redefinition of research and pedagogy. IN the long term, we aspire to create a world-class academic center on par with – but not a clone of – the world's greatest research universities."

For more information on working with Albany NanoTech, contact Michael Fancher, director of economic development at mfancher@uamail.albany.edu Also: http://www.albanynanotech.org and http://cnse.albany.edu.

BIOGRAPHY FOR MICHAEL FANCHER

Michael Fancher has been the Director for Economic Outreach at Albany NanoTech, University at Albany—SUNY for over six years. During that time he has supported the development of partnerships with high technology companies, industry consortia, governmental entities, research institutions, private financing and not-for-profit organizations. Specifically, he identifies opportunities to leverage financial, technological and market development resources by formulating strategic application-specific and technology-driven development programs. Michael also supports the business acceleration initiatives by coordinating federal, State and local financial and technical assistance programs for high technology business enterprises through each stage of technology commercialization. Mr. Fancher holds a Master's degree (international economics-finance) from the University at Albany-SUNY, an undergraduate degree in business administration (accounting & finance) from Syracuse University and is a Certified Public Accountant in New York State.

Prior to joining Albany NanoTech, Michael served as Deputy Budget Director for the New York State Assembly Ways and Means Committee overseeing project development financing and program policy structures supporting university research, regional infrastructure, energy industry restructuring, public & private construction projects, environmental protection, procurement reform, transportation capital planning & industry regulatory issues. He was awarded the Governor's commendations for legislative achievement supporting business competitiveness and project development financing.

As a Certified Public Accountant, Michael has provided audit, tax and financial planning services for business formation, expansion, merger and acquisitions and is experienced in financial and economic modeling.

UNIVERSITY AT ALBANY
State University of New York

College of Nanoscale Science and Engineering

Alain E. Kaloyeros, Ph.D.
Vice President and Chief Administrative Officer

James Castracane, Ph.D.
Associate Vice President

August 10, 2005

The Honorable Bob Inglis
Chairman, Research Subcommittee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Inglis:

Thank you for the invitation to testify before the Research Subcommittee of the Committee on Science of the U.S. House of Representatives on May 18th for the hearing entitled "***The National Nanotechnology Initiative: Review and Outlook***." In accordance with the Rules Governing Testimony, this letter serves as formal notice of the federal funding received by the Research Foundation of the State University of New York on behalf of the College of Nanoscale Science and Engineering currently receive related to the hearing topic.

Amount	Grant #	Federal Agency	Fiscal Year Received (End Date)
$412,717	29972	National Science Foundation	2006
$174,967	30317	National Science Foundation	2006
$76,558	31931	National Science Foundation	2006
$1,774,120	35979	US Navy Office of Naval Research	2006
$1,603,018	32900	US Navy Office of Naval Research	2005
$38,046	33761	US Army	2006
$347,228	30986	US Army	2005
$58,457	29252	US Army	2004
$58,430	30961	US Army	2004
$1,362,448	35652	NASA Glenn Research Center	2005
$88,440	34455	Dept of Energy	2007
$51,632	30578	Dept. of Energy	2005
$40,823	31002	Dept. of Energy	2004
$343,243	27556	Dept. of Housing & Urban Development	2003
$37,170	32780	Dept. of Education	2005

Sincerely,

Michael Fancher
Associate Professor of Nanoeconomics,
College of Nanoscale Science & Engineering

NanoFab 300 South, Suite 214
255 Fuller Road, Albany, NY 12203
PH: 518-437-8686 FX: 518-437-8603
www.albanynanotech.org

DISCUSSION

Chairman INGLIS. But while you have got that slide up, let me ask you the first question, if I may.

Mr. FANCHER. Yes.

Chairman INGLIS. You were actually in the process of answering a question that I had, and perhaps others on the panel have, which is where is our main competition? Who should we be concerned about?

Mr. FANCHER. I think, when you look at the competition from abroad, you are seeing the European Union as a very strong block that invests heavily in supporting the business—the similar model as what is at Albany NanoTech. When you look at Asia and Japan, they also have formed a similar model in Japan. France has also established in Grenoble, a similar model. So the model is validated, I think, by—but the competition—and the focus is similar. They are focusing on developing the expertise in this process technology to not only provide a platform for nanotechnology, but to take the knowledge base of processing and apply it to rolling production for photovoltaics, all types of different production of materials and substrates.

Chairman INGLIS. That is helpful.

Mr. Donnelly, I should have mentioned that we are extremely happy to have General Electric in our District making gas turbines. I saw that operation recently. Amazing that you can run gases over those rotors that are the higher—the gases are being at a higher temperature than the melting point of the metal that comprises the rotors. It is amazing.

So perhaps you—because you are in business at General Electric to make products, tell us how we, in the Federal Government, and folks like Dr. Kennedy in academia and Dr. Cassady, can help you get to products. What can we best do here in government and in the university to help you get a product into the marketplace?

Mr. DONNELLY. Well, all I can say is it is in two parts, Mr. Chairman. One is certainly students coming out of universities. So again, the funding that goes through NSF, you know, the people that try to figure out how to make those materials survive beyond their melting point, which is actually the tricky part of these systems, is all of that intellectual capital. So the, you know, the talent that we are able to bring in out of university systems on a constant basis to design that next generation is incredibly important to us.

And other avenues that we see in terms of the federal role in things like next generation aircraft engines, you know, it is—you can't state the importance of where the military tends to go with things like JSF engine technology, which is important, obviously, for the military mission perspective. But that technology then floats and works its way down through our commercial aircraft engines, our energy businesses, and things like that.

So I think when you look at the programs that the Federal Government funds, it helps to pull a lot of these very high performance, leading-edge technologies that might first show up in a military application but ultimately work their way into a commercial application as well. The same is true in the energy area. If you look at the DOE funding that is in place to help support and bring some

of these new technologies to the market, frankly, before they might be economically suitable for wide-scale deployment, it is a very necessary step to get that technology out on the marketplace and start working on the cost and validation of that, which ultimately ends in a very large business.

Chairman INGLIS. Okay. Dr. Kennedy, what do you think we could do, we, in the Federal Government, could do to help you accomplish your objectives of——

Dr. KENNEDY. I feel like that in terms of translating—transferring nanotechnology into companies, you need graduate students that have broader perspective than just how to make polymers or how to make this nano-material, because they don't have it—they really don't have a business experience in their graduate education. And we are looking at that as universities, but one of the things that has happened in the polymer industry that we, as an ERC [Engineering Research Center] and the polymer industry, now are facing is central research at the polymer industries that was downsized because of globalization. And that is a void that now exists in commercialization. And the government and the universities really need to think about how that void can be replaced. And that is something that our center is actually thinking about right now.

Chairman INGLIS. Dr. Cassady, anything to add there from your perspective?

Dr. CASSADY. Well, I think it is interesting to look at this industry and maybe compare it a little bit to the biotech industry that developed. And I think that you really have two types of corporations that are moving into these fields. You have the GEs, the major, large corporations, but you also have a lot of start-up companies. I think if you look worldwide, and this is based on data, that probably about half of the start-up companies in this area are in the United States. So we are not doing too badly in terms of getting the companies to that stage. But if you actually look, government investment is as much in this area as corporate investment. So I think that there is a problem there in getting the 600 start-up companies into a stage where they can develop through investments. So to me, I think gap funding is important. At the university level, I think it is important to be able to protect intellectual property. One of the things that we don't have at the university is a way to operate like a business. For example, we have a lot of good ideas and innovations and intellectual property, but how do we pay to get those protected? And then once you have a—I guess I would call it almost an idea for a product, how do you get it through that gap so you can actually develop it into a product? And that needs investment.

So I think that those are areas that need to be looked at. If you really want to talk about getting the innovation, especially out of our universities, into something that becomes a product or a company. I think there are only six nanotech companies out of the 600 in the United States that have received a second round of venture capital funding. And that, to me, is pretty limiting.

Chairman INGLIS. Thank you.

I am happy to recognize Ms. Hooley.

Ms. HOOLEY. I want to yield to Mr. Honda for a follow-up.

Mr. HONDA. Thank you very much.

The comments to—the answers to the question of the Chair were very intriguing to me, and I have been reading through your testimonies, and it seems like there is one conclusion I come to on the question of what role the Federal Government has in commercialization. I think I heard Dr. Cassady say that we need to have gap funding. I hear other folks saying that there is a role—definite role of Federal Government in bridging the "Valley of Death" so that research can reach commercialization in this area. This is not a nano industry. It is a nanoscale activity, which is an enabling technology.

And so my question is, given the kinds of things that are going on today, and from your point of view, what is the further role—or what is an additional role that the Federal Government can play that may be considered by some folks in the Federal Government as corporate welfare? But it seems to me that we—in this new arena of nanoscale activities, that the Federal Government has a critical role to play with universities, start-ups, and established corporations to be able to help and assist in bridging this gap until we have reached that critical point where private investors can come in with some confidence and support commercialization. Is there a comment from any one of the four of you? And perhaps we could start with Dr. Cassady and then work to Dr. Kennedy and——

Dr. CASSADY. In the discussions that we have been having, one of the points that was made is that we need, and to be really frank with you, this is a new terminology to me, but what the military calls "6.2 funding." It is DARPA type funding. And I think that the people at ONAMI feel like that there is a need for this sort of funding for this area. And again, I think that there is a role of government. And I know in some of the current discussions at the state level in Oregon, there is an issue that is being raised with regard to trying to attract more venture capital into this area. So part of it is that. We have a fairly good environment in Oregon.

Mr. HONDA. But what I am hearing you say is that there is a model out there that it should be applied to——

Dr. CASSADY. There may be a model, I think, that you could look at.

Mr. HONDA. And in spite of the fact that a lot of pressure is being put on states that the Federal Government still has a role?

Dr. CASSADY. I—you know, I would add another piece to it, because I think, you know, the collaboration between federal and state is going to be needed in order to optimize this approach.

Mr. HONDA. And to the Chair. Would this enhance our competitive edge globally?

Dr. CASSADY. I would think so.

Mr. HONDA. I just needed an opinion from the field, that is all. Perhaps the others have some more comments.

Dr. KENNEDY. I would like to reiterate some of my comments that the NASA activity 25 years ago, we had done a tremendous amount of research on composite materials. And the push that NASA provided and DOD provided by developing components for aircraft, such as wing flaps and wing boxes, really helped the industry. It pushed the industry to develop that technology. I think that is an important step that the Federal Government—and that

is consistent with the comment you heard on DARPA. So DOD, NASA, Department of Energy, those are some wonderful places where demonstration programs could benefit nanotechnology I think.

Mr. HONDA. I appreciate your patience. What you are talking about is basically a paradigm shift in how we do things, and this composite research took, what, 20 or 25 years to get to the point of commercialization? Is that something that the private sector can afford to do, given the time?

I know the answer is no. The Federal Government—what you are saying is that has a critical role in helping to bridge this end.

Dr. KENNEDY. Well, the Federal Government funded that activity for——

Mr. HONDA. Right.

Dr. KENNEDY.—a very long period of time. But now what you are seeing now is aircraft that are having 50 percent, or a large fraction of their structure, made out of composite materials, and it just—it takes a while for the industry to develop the confidence to put something on an airplane where you have—where there is potential for disaster. So there are a lot of issues there.

Mr. HONDA. And the composite has been applied to the tail section of our commercial jets now. It is stronger, lighter, and more reliable. And this could be applied to, say, launching of satellites that could be lighter and stronger and carry a heavier payload and things like that.

Dr. KENNEDY. And that is where nanotechnology—those are opportunities for nanotechnology, I think.

Mr. HONDA. Thank you.

Chairman INGLIS. Mr. McCaul is going to be recognized, but he is going to come and take the Chair for a moment while I run to a vote in the Judiciary Committee.

So Mr. McCaul and the Chair.

Ms. HOOLEY. He came a long way.

Mr. MCCAUL. [Presiding.] Yeah, I appreciate the promotion from being just a lowly freshman to the Chair of the Subcommittee.

My District is from Austin, Texas to Houston. I have got high tech on either end. I have Dell, Samsung, Applied Materials. I also have the University of Texas, and so I have the research and development arm of the university. And I am very interested in this issue of nanotechnology as it applies to what I view as really a great partnership between industry and the universities. We have a lot of scientists at the universities that are interested in this partnership. I think it is good for industry as well.

So I wanted to see, first, if you would comment on that, and then specifically, if you could discuss two issues. One is computer models being funded by NSF. I know that with the UT system that is very important with respect to nanotechnology. And then, second, in terms of the industry's collaboration, there is always the issue of intellectual property management and how they can properly protect intellectual property.

So I know I am throwing a lot out there, but if—just to the panel as a whole, if you would comment on that.

Mr. FANCHER. Well, I will take a stab at the modeling, if you would like.

I think it is important. You know, a science is a science, while it is limited to just an experiment, you get one data point, and you don't really have predictability in it if you change variables in that experiment, which is what is required for a manufacturing process. So once you have more predictability, it is just to turn into a technology. And that modeling is really a precursor or a critical event that has to happen in manufacturing so that you can start to have the confidence to control that production process to know that as you are changing your inputs a certain way, what the outcome will be.

So that would be my—so yes, it is critically important.

Dr. CASSADY. I will take a stab at the intellectual property.

I think that each institution is different, but I know at our institution, we have—and I would guess that probably the other Oregon institutions, we have to look at our process. I made the comment that we have to make it easier to do business with the university. And that is one of those barriers that occurs if you have too many steps in the process to approve these transfers of intellectual property and licensing.

The second thing is partnerships. I think that we have to find a way to make these work, and I like the idea of trying different models around the country and then learning from one another as to what works and what doesn't work. And I think our experiment is going to be very interesting.

I come from a background that was involved in—where NIH National Cancer Institute funds partnerships, inter-institutional, and always involving a pharma partner in what they call "national cooperative drug discovery programs." The bottom line, you want drugs, you want NDAs, and you want drugs going on the market. And I think those types of partnerships are excellent, and they are excellent places for students to learn.

Dr. KENNEDY. I would like to comment both on the intellectual property issue and on modeling, but I will pick modeling first.

Our engineering research center was funded based on modeling. It was our view that we could help the fiber and film industry transform from a trial-and-error industry to a predictive industry, but that would require that we do modeling at both a core scale, which we call a continuum scale, and at the molecular level. And we are doing that now.

But let me point out the kinds of advances that we have made. The initial algorithms that we were using to compute at the molecular level were indicating that to get an answer, it would take thousands of years, 10^5 years. We have modified those algorithms to the point where we can get that answer in several hours. That is a major advancement. But it still takes powerful computers and excellent computer infrastructure to do that. So we are making progress, and we are training students to use modeling in the fiber and film industry.

Concerning intellectual property, I heard a woman from the Dow Company talk about their interaction with universities. And she pointed out that universities need flexibility in the way they approach intellectual property, and she was saying that it had been their experience that universities were very rigid in that regard and so much so that Dow was starting to utilize industries in other

countries. Particularly, they are going to Europe to get research done. It says that the universities really need to take a hard look at that, and I think that has been suggested here. And it is something that we need to do.

Thank you.

Mr. DONNELLY. I would comment on the modeling side. This is very important. It has been important for many years in terms of, first, gaining a better understanding of what is going on. And in terms of the cycle times for material systems, you reference the composites that took 25 years.

This is quite common in any material system, nano or otherwise. The cycles are very, very long, and utilizing modeling to understand better what is going on and reduce the number of experiments is very important, especially as you get to the nano level. The degree to which you can experiment and truly understand the material behaviors is very, very difficult without augmenting that with a good modeling program. And so that is very important.

IP from an initial standpoint, I can echo the Dow position as it has been articulated. Frankly, it is an enormous barrier to working with universities. I would say there is a great deal of variability. Some universities are very good to work with in this regard. Others are on the other end of the spectrum and virtually impossible to work with. And so it can be a significant barrier. The need to invest a great deal of funding over a long time and not have good IP terms and exclusivity, in many cases, frankly, just leaves industry to have to walk away and look other places for this capability, because having that intellectual property ownership is very important commercially. You really can't do it without it.

Mr. MCCAUL. Well, thank you.

And of course any suggestions to enhance that industry-university relationship, I think the universities, to be competitive, sort of need to get with the program, so to speak, and start working. I think some have worked very effectively, and Dr. Kennedy, I was actually concerned to hear that some were not, but I think it is a great partnership for America.

So the Chair recognizes the Ranking Member.

Ms. HOOLEY. I didn't realize I was giving away all of my time to Mr. Honda, but that is okay. I thought you were going to ask him a short question.

I am going to ask just a couple of very—I had some specific questions, but many of them have been asked—some very general questions. One is if there was one thing that we, the Federal Government, could do differently that would help us really be at the head of the class in terms of global competition, what would it be? And I will just start at one end with Mr. Donnelly and go to the other end.

Mr. DONNELLY. I think if you will look in—and this was—I referred to it a little bit earlier in the question by Mr. Honda, but when you think about new material sciences, of which nanotechnology is sort of the central theme of that right now, these are technologies that can bring a lot to new applications. That is how we have to look at it. At the end of the day, we are not doing nano because nano is something to do, but because we want to improve performance characteristics of some end application. It could

be an aircraft engine. It could be a medical scanner. Any number of different things.

Where the Federal Government can play an important role in that is more funding in the early stages of science and much more focused on the "R" side of R&D. References were made to NASA and a number of other military application programs. That money that is—you know, whether it is 6.2 money and things of that genre are really where that kind of research activity goes on for many years before you really get the technology insertion. And there are plenty of applications across our military and NASA and NIH where we have challenges in terms of things we want to achieve in new areas where new material science is ultimately the answer to that, but they are things that need to be nurtured for a number of years to really put money into that science side of it before you are going to see that in the end application.

Ms. HOOLEY. Okay. So you would say more money into the research side?

Mr. DONNELLY. More money into the research side, more money into the 6.2s, more money into the real challenges we have in NASA and DOE and DOD and areas like that.

Ms. HOOLEY. Dr. Kennedy.

Dr. KENNEDY. More money is always wonderful, but I think we have also got to look at workforce, very definitely. And when I say workforce, I think we have got to back up into the public education system and figure out ways to excite pre-college students about science, mathematics, and engineering. We graduate 56,000, I heard, engineers a year, and China's goal is to graduate a million engineers a year. Well, the competition—you see where the—they are great minds. So we really need to reach out and involve other people in science and technology, and the Federal Government needs to think about that. And they are doing that. We have outreach programs that we participate in, NASA does, but we have really got to continue to push hard on that, I think.

Ms. HOOLEY. Dr. Cassady.

Dr. CASSADY. Well, I certainly agree with both of those conclusions. I guess that my feeling is that something that would encourage the relationships between research teams in the research universities and these start-up companies in this industry that don't really have the R&D funding, I think that, to me, is a place where you could have a big impact. You know, there is something wrong when you have 600 start-up companies, only 10 percent of those got a first round of venture capital funding, and only 10 percent of those got a second round. So you really have a big gap there.

The other point I would make is in terms of the workforce. Are there some issues that I think surround some of our concerns about national security that could have a big modulating effect on our ability to attract graduate students, international graduate students? Now I am very concerned about that. So I think if, you know, we don't want to have a double-edged sword where all of a sudden they are gearing up, which they are, and then we make it less available because of certain regulations that may be placed. I am thinking in terms of export control, for example, as an area where we are seeing a potential really big impact on our ability to

bring graduate students in from certain places and have them work as part of these teams.

Those are a couple thoughts that I would have.

Ms. HOOLEY. Before we go to Mr. Fancher, I want to ask a question.

Is there the—being able to bring in graduate students or college students from other countries, is that a big problem for other universities? No?

Dr. CASSADY. Well, I am talking about a potential problem and the potential impact of export controls.

Ms. HOOLEY. Okay.

Dr. CASSADY. For example, where we may be actually in a situation where we have to get students from certain places licensed to be able to have access to certain equipment to do their research.

Ms. HOOLEY. Okay. Okay.

Dr. CASSADY. And if you do that, and I am not saying that we have gotten to the point where it has been done, but if you do that, I think it will have an impact on where students decide to come and do their graduate work.

Mr. FANCHER. Finally, I would say you are probably beginning to observe several states have entered the game of nanotechnology in a, I think, very complementary way to federal investments. But I think what you also are seeing is that there is a—I kind of am complementary to Scott's comments about focusing just on research. I think that it is time to begin focusing on the development and early manufacturing that the nanotechnology has come out of the lab and it is now ready to go into commercialization. And our competition is focusing their investments heavily in what I would call "next generation Bell labs." PCAST noted that in their study back in 2003. There is a—the cost is daunting to commercialize nanotechnology. It is increasing exponentially. We are producing lots of wonderful research, but to capture the economic rewards requires a focus on supply chain, getting your partners, leveraging the resources from the states, leveraging the resources from companies, industry to tackle that. And I think other—competition is doing that, and if we just look at the number of papers that are published, what you are going to be focused on is the success in the research, but we are not going to be fully realizing the benefits of development and manufacturing for homeland security, defense, and all of our other economic security.

Ms. HOOLEY. All I know is having visited ONAMI and not having quite the wonderful floor space that you have in—facility that you have in New York, that a couple of the products that have been—are in the stage of being developed really make a difference in people's lives. I mean, it is amazing what nanotechnology can do and really transforming how people live. And so it is—I mean, I think it is really important work you are doing, and I like the partnerships. And if you would—please, if you have any suggestions about what we can do and what we can do better, let us know.

Thank you so much for taking your time to be here today.

Chairman INGLIS. Thank you, Ms. Hooley.

I will recognize myself for another round of questions here.

Mr. Fancher, it was very interesting to hear you talk about hands-on kind of learning, I think, in one of your slides. And the

engineering statistics that you cited are of great concern to us on this committee, and we have talked about it a number of times here. And it seems to me, as a lure, that one of the things that would make engineering more interesting is if it is, as much as possible, hands-on education, so that it is not an abstract principle, but rather something that, "Oh, I can see how that might work." And if you can see it, then it is an exciting thing to study. Like the law has stories that it tells in its cases. It is interesting to study law, because they are about people and they are about cases and they are about situations. If you make engineering that interesting, then hopefully we will keep a lot of students going at it.

Another thing I wanted to comment on is the—I think I have heard comments on collaboration both in Mr. Fancher's testimony, and I wanted to congratulate Dr. Kennedy on what Clemson is doing. It really is significant, I think, that Clemson University is teaming with MIT. That is obviously significant, and with Clark Atlanta University. That is an exciting thing that you realize that your commitment to diversity and to expanding this—opportunities for engineering education from MIT north of you to Clark Atlanta University south of you, and so I wanted to congratulate you on that.

Now what is the—those of us that are new to this nanotechnology get very excited about it. But help me to figure out the difference between what we should be expecting here and the hype. We have to be careful, I suppose, those of us that are novices at this, not to be carried away and think that we have found a perpetual motion machine or something like that and go running out and tell everybody to buy heavy in those areas. So does somebody want to help me figure out the distinction between the reality and the hype?

Mr. FANCHER. Well, I will take a stab, not to miss out on that opportunity.

I think the hype a lot of times is what is often described as "bottom up nanotechnology." And it is the concept of basically creating something molecule by molecule exactly the way you want it. Think of it as a statue from the inside out. The more closer to commercialization, though, is the top-down approach where you are integrating nanotechnology in incremental ways. And I would give an example. Maybe you are familiar with microsystems or MEMS. Okay. Well, game-changing performance improvements can be made or captured by integrating nano-materials onto these microstructures. So it is the—it is an incremental process, or an evolution of nanotechnology versus there are isolated examples of the revolutionary impact of nanotechnology. For example, the clothes that don't absorb dirt. You know, there are a few, but those will be fewer and far between. The other wins, I think, are going to be an incremental evolution. And the reason for that is that your supply chain—you know, just because you invent something, I mean, doesn't—you have to bring the whole supply chain along with you before it goes into production. The tool suppliers, materials, the chemistries. And it is one thing to make just one device. It is quite a completely different challenge to make a high-yield, low-cost production flow for that. It is a completely different challenge. And I

think that is my—I hope that I—you know, at least from our perspective would kind of——

Chairman INGLIS. That is helpful. And Mr. Donnelly, something that you mentioned is interesting. You said R&D, we should really be focusing on the "R" part of that in government. And yesterday, I was with some folks from General Motors, and that is really what they were saying about hydrogen, that we really need for the government to be taking risk in the "R" part, I suppose, in your terminology, and leaving to companies like yours and General Motors to pick up from that. But tell me how you see that "R" part, the risk taking in the research area. I mean, that is, I assume, what you would say is what government has to do is take the risk in the research.

Mr. DONNELLY. I think that is true. And not the sole responsibility, obviously. Companies like ourselves are investing in the basic research, and we will continue to do that. But I think what happens, if you look at the government and willingness to take risk is to provide some early application opportunities for these technologies. I think one of the challenges in nanotechnology and for people to understand nanotechnology and sort of what is involved in this process is, perhaps, more difficult than a lot of other technologies we have talked about, because if people are expecting that, you know, some day, whether it is a year or 10 years from now, you wake up and start buying nanotechnology products, people are really confused. I don't know what a nanotechnology product would be. Where the nanotechnology is going to be, it is truly enabling technology. So whether you are talking about enabling a technology that would allow more highly efficient ways to convert water to hydrogen, to enable the hydrogen infrastructure, or whether you are talking about an aircraft engine that gets, you know, better fuel economy because you can fire at a higher combustion temperature because of a nano-alloy and a high-pressure turbine blade, the places where the technology is going to make an impact, it is not going to be terribly obvious. And 99.9, probably, out of 100 people in this country will never understand or know there is nanotechnology in the product they are buying. It is the change in that technology that is enabling that better performance or that higher reliability that is how the impact of nanotechnology manifests itself. And so it is hard, really, to go to the public and say, "This is what nanotechnology is," because it is many different things, and it is going to manifest itself not as a nano-product but as something in a bigger product, everything from a semiconductor chip that runs at a higher speed or higher transistor densities to an aircraft engine turbine blade.

So I think when you look at what the government role can be, and why I say to focus on the "R" side is that historically, the government applications, whether they be for security purposes or military purposes or energy infrastructure purposes, can have these challenges that can be solved by new material systems. And that is where I think the government can take those risks in those early applications and allow the technology to mature before it shows in the commercial sector.

Chairman INGLIS. Thank you.

My time has expired, and I would recognize Ms. Hooley for a second round of questions.

Ms. HOOLEY. Thank you.

Mr. Donnelly, I am going to ask you this question, and then the rest of you can answer it afterwards.

Bridging the gap between research—basic research and nanotechnology commercialization, as you have just explained, is an enormous challenge.

The Advanced Technology Program at the Department of Commerce was designed to address this transition problem. And it currently supports projects in the nanotechnology area. Do you, or any of you, believe—or have had experience with this program, and if so, do you believe it is valuable and deserving to be continued—the support continued for it?

Mr. DONNELLY. Well, I am familiar with the NIST programs. I probably should preface by saying I am on the NIST Advisory Board, and so I am—or the ATP program, and so I am familiar with their programs.

Ms. HOOLEY. Okay.

Mr. DONNELLY. And I think they do have value. They do encourage promotion of very novel, early-on technologies and promote the interaction, frankly, in many cases, between companies both large and small and universities and other small companies. And so I think that is an area on the research side where it has provided some funding to develop some novel technologies in clearly what is a pre-commercialization state. And so it is not necessarily targeted at an application that is DOE related or DOD or NIH related but really provides an avenue that historically will fund some very early technology, pre-commercialization, and does promote what I would kind of refer to as some "R" funding well before you know where that application is going to go and where the development phase will go.

Ms. HOOLEY. Do you think it has been successful?

Mr. DONNELLY. I think it has been largely successful. Again, it is a case of the government taking some risk and investing in some early technologies, and so you certainly would look at some of those programs and say, "Nothing came of it." That is truly the nature of research.

Ms. HOOLEY. Right.

Mr. DONNELLY. And we have to look at that as well. We invest in many things that don't happen, but some of the things turn out to generate some technologies to become very commercially important.

Ms. HOOLEY. Do any of the rest of you have experience with that program and—yeah, Dr. Kennedy?

Dr. KENNEDY. Yes, ma'am. We have been very interested in the ATP program as our NSF money runs away and goes away in another three years, and we are looking for supplemental funding to keep our center running. And that is one of the places we will look is at ATP with our industry partners, because we do have 20 industry partners. So we are very positive about that program.

It is not a big program. It is only, what, $200 million to $300 million, I believe, so it is not really, really big, and—but I think it is a good idea. We have attended a number of their workshops, and

so we are pretty positive about it, and we would like for it to stick around.

Mr. FANCHER. I would also comment. I think the NIST ATP program is extremely effective. And the reason for that is that it provides for the integration of several companies' technologies to work—to be integrated together. It is the funding to allow for those types of mid-range programs that are so critical to commercialization. So it is really pre-commercialization, but it is—and I think NIST does a nice job of focusing on taking—selecting high-impact opportunities, things that are—you know, yes, there is risk, but if it hits, it will provide a broad impact on a variety of other companies that—for example, tool development or something like that. So——

Ms. HOOLEY. Dr. Cassady, any——

Dr. CASSADY. I am not that familiar with the ATP program.

Ms. HOOLEY. Okay.

Dr. CASSADY. But SBIR I am more familiar with. I think that that also plays a role in helping with early stages of business development. And that has actually been a mechanism to help faculty that wish to do this actually move into a business development phase. And that has been done very successfully in certain areas, and we just need to figure out how to make that process more efficient. But that is another mechanism that helps fill that gap.

Mr. FANCHER. I think it is also important to note, venture capital does not tread there. And everybody thinks——

Ms. HOOLEY. Right.

Mr. FANCHER.—venture capital is early. No, venture capital——

Ms. HOOLEY. No, venture capital wants to be where they know they are going to——

Mr. FANCHER. It is there generally where there is production already in place.

Ms. HOOLEY. Yeah.

Mr. FANCHER. There are sales, and they are ready to take it global or something. There is a lot of research——

Ms. HOOLEY. They are not risk-takers.

Mr. FANCHER. Yes. There is—a majority of the funding is in the research realm, very little in this development mid-range. And you are seeing it from NIST ATP. DOD, when they need something for the battlefield, they will fund in that space. And then Department of Energy, also. So there is—I think it is important to understand—and PCAST mentioned it. Research and development and manufacturing, they are two pieces of it. They co-exist, and they feed back and forth. And that is back to the workforce training. How do you do hands-on workforce training if you are only in the lab? You do work for hands-on exposure, because you have got actual, real-life—this is what your work environment is going to be. This is what you are going to get, you know, to work in with these kinds of tools or in this environment. And I think that is very engaging. Particularly, we expose kids in high school, even the vocational student kids are being brought in and rotated through. And in fact, our region, they are actually pushing forward to build a new high-tech vocational school focused on this, and it really creates, I think, an avenue, a strategy for engaging a restructuring of the educational curriculum that is nano-centric, let us say.

Ms. HOOLEY. I think it is interesting that you are looking at high-tech vocational training, because, at least in my state, when I look in the newspaper and look in the help wanted ads, the number of jobs tend to be in the highly skilled area. I mean, they are asking for not particular engineers, but highly skilled workers in a variety of things. And that seems to be where we are missing the boat. So I think it is interesting that you are looking at high-tech vocational programs.

Mr. FANCHER. Yeah. Well, if you were to look at a chip fab, a large chip fab, about 2,000 workers in it, about 20 percent of those are Ph.D.s and engineers. The 80 percent are operators, technicians. You know. I mean, you can—they make very good money——

Ms. HOOLEY. Right.

Mr. FANCHER.—fixing these tools without even an associates degree. You are global. You are in demand. I mean, it is a very exciting opportunity. And what is nice is that there is a whole continuum so that you can go back to school. There is a—it is a nurturing—the industry provides—or the nanotechnology, I think, promises to have a whole continuum of opportunities for a worker to pursue lifelong education and training to work their way up the—you know, the pay scale and the technology responsibility scale.

Ms. HOOLEY. Thank you.

Chairman INGLIS. Thank you, Ms. Hooley.

Mr. Honda is recognized for a second round of questions.

Mr. HONDA. Thank you, Mr. Chair, and I hear a bell ringing, so I will be real quick.

I want to thank the Chair and Ranking Member for putting this together. And the four of you have made today really a day well worth living, because the kinds of things that you are sharing with us is the kind of information that we need to hear constantly, because there seems to be some—at least in my opinion, some foot-dragging in this arena.

I agree that we have to do a lot more in pre-high school education in the area of education and bringing along the community in terms of they are being critical consumers of products and also the idea of having ATP continue, which has been zeroed out.

And I guess—there doesn't seem to be a disagreement also on the role of government in bridging the gap. My question would be, given that, how do you see us creating the solution set for the problems that you have described? And you know, with the short time, I would love to have that in writing so that it would give us a little bit more time to cogitate over the responses you may have, the solution sets that you may be suggesting from both the corporate, to the university, to the research arena. And that would be something that I would really love to have, because we are struggling here to be able to address everything from ATP to funding the gap.

Thank you, Mr. Chairman and Ranking Member. And if you have an immediate response, I will take it.

Mr. FANCHER. I would love to take a shot at that.

Actually, my written testimony, at the very end, it has my recommendations.

I think, just as in the past four years of the nanotechnology initiative, investments were made in strategic critical research infra-

structure. The National Labs, for example. Significant amounts of money were invested in the National Labs in key areas of nanotechnology, the same as NNI provided for key research at a variety of universities around the country. I think what is important to understand that—to help the smaller and medium-sized companies through the "Valley of Death," you can try to do it grant by grant, company by company, but you end up with winners and losers, and frankly you feel like you didn't get your money's worth. I think what is important is to begin to focus on focusing the investments in national resources. Ours, for example, is at—we view ourselves as a national nanotechnology resource. It is $3 billion of investment there. To not leverage that for small and medium-sized companies in a variety of applications is a huge lost opportunity. The same, though, for rolling production of—in polymers and fibers. There are different challenges there, but there is a need to focus the investment in key integration points. I think PCAST calls it "innovation clustering." Now it is not to say that all of the jobs happen there. It is that middle that—what NIST ATP is trying to do, you are supporting it through infrastructure, and that lowers the risk, lowers the cost for the companies to engage work together, leverage each other's resources, and pull their resources towards a common end. And I could envision having centers like this established around the country in—focused on different production or applications for nanotechnology, depending on the particular area and in—of advancement. Certainly Europe is doing it. Asia is doing it. If we don't do it, I think we are going to find ourselves losing the economic rewards.

Dr. CASSADY. I would be pleased to provide further responses after I consult with colleagues, but I think the idea, and the idea that we are pursuing at Oregon State, is very similar, that is creates centers of innovation. Our research universities are centers of innovation, but find a way to create places where we can translate that out in a way that is more than rhetoric, that—where it actually occurs. And you need places where you can bring these teams together to move these ideas into products and eventually into businesses.

Chairman INGLIS. The gentleman yields back.

And I want to thank you all for coming. As you hear, we have got votes on over at the House Chamber. Thank you for allowing me to run out to a couple of votes at the Judiciary Committee. As you see, we get our good exercise around here.

And I very much want to thank you for coming to share your thoughts. It has been a very helpful hearing for me, and I am sure for others. And we look forward to working with you on these exciting developments.

Thank you for coming.

[Whereupon, at 11:45 a.m., the Subcommittee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by John M. Cassady, Vice President for Research, Oregon State University

Questions submitted by Representative Dave G. Reichert

Q1. Under funding from the National Science Foundation and the Defense Advanced Research Projects Agency, researchers at Washington State University in my state are using nanotechnology to develop new energy production systems based on piezoelectric materials and nanotubes for energy switching. Although such technologies have significant potential for security and consumer applications, development of the technology for applications can be expensive and time consuming.

Q1a. What role could national laboratories play in helping move significant new technologies enabled through nanotechnology from university research to applications?

A1a. I believe the best group to answer this would be our national laboratory administrators. We are working very closely with PNNL and I will discuss this with my counterpart there, Dr. Len Peters. Question is how they would view in-licensing. The partnerships we now have to develop joint proposals lead to access to support that academic PIS normally do not have. In some cases, this may lead to development.

Q1b. When multiple organizations, all of which are funded by the Federal Government, are involved in such work, how can the universities continue to receive appropriate credit in accordance with the Bayh-Dole Act without directly licensing the technology to the national laboratories for further development?

A1b. These relationships are framed by agreements (MOUs) that address issues of licensing, commercialization and revenue sharing. That is if you mean by "appropriate credit" licensing income. These agreements are always negotiated up-front. The national lab might have first right-of-refusal on licensing the technology and could be involved in further managing development.

These responses had input from Skip Rung, Director, ONAMI.

Appendix 2:

Additional Material for the Record

STATEMENT OF BOB GREGG
EXECUTIVE VICE PRESIDENT
FEI COMPANY

Chairman Inglis:

Thank you for providing the opportunity for us to express our observations on the National Nanotechnology Initiative.

I am Bob Gregg, Executive Vice President of FEI Company. Our corporate headquarters are in Oregon, and we have 1,800 employees. Our association with nanotechnology derives from the tools we build and the diverse international markets and customers that we serve. FEI develops, manufactures, distributes, and services transmission and scanning electron microscopes and dual ion and electron beam tools. Our tools enable nanotechnology by allowing materials and devices to be observed over a size range of eleven orders of magnitude. The tools are used to observe, characterize, manipulate, and modify structures. They allow human vision to be continuously extended from the naked eye to the macro- and micro-worlds, down to the meso- and the nano-scale and below. Because of the existence of these tools, the imaging of atoms is routine. This level of performance capability is necessary to further not only basic research, but also to enable industry to manufacture at economic levels of yield. Our products are used worldwide in academia, institutes, and industries for research, prototyping, and production. FEI's designated markets are NanoElectronics, NanoBiology, and NanoResearch. Our sales revenues are evenly distributed among the Asian, European and North American markets. In 2004 our revenues approached $500 million.

We have been selected by the DOE as the primary contractor on the TEAM project which is intent on building the highest resolution electron microscope in the world. This instrument is targeting subatomic resolution levels and will lead to a new generation of more powerful research tools. FEI Company is also actively pursuing initiatives with government entities in the area of researching proteomics and in technical education.

As a consequence of our business activities that are on the forefront of nanotechnology developments, we believe that we can offer a unique global perspective on the National Nanotech Initiative and its impact on U.S. economic development.

Our comments are directed at actions that are needed to stimulate a more direct connection between academic science research and the economic growth of the Nation. The task is to prioritize and then channel the basic research we require into the academic research community in order for U.S. industry to meet its strategic objectives. The need is for a structured and sustained dialogue between U.S. industry and Government research policy makers. If we do not succeed in this, the U.S. will become a net importer of foreign nanotechnology-based products in the future with serious negative consequences to the social welfare and standard of living of all U.S. citizens.

We restrict our observations to the following points.

1. The announcement of the National Nanotech Initiative in the year 2000 had the purpose of stimulating and directing science to create a platform for new technologies and, by implication, a basis for maintaining economic growth. The initiative has succeeded admirably in revitalizing U.S. science. It has also had the effect of catalyzing other nations and economic blocs to actively compete for predominance in a future nanotechnology-based global economy. The U.S. now trails government investments in nanotechnology in Europe and Japan. This impacts our potential for innovation and, in turn, threatens our future economic growth.
2. Competitive government bodies appear to have taken a business approach in positioning themselves for future success. The fundamental difference with the NNI approach is that other governments are gearing their strategies to rapid commercialization of nanotechnology. The objective is a rapid return-on-investment. Their approach is to focus their efforts into specific industrial enterprises that play to their strengths and then provide direct government investment to industry to accelerate product time-to-market.
3. It can be argued that the commercialization of nanotechnology is made more complex within the U.S. free-enterprise system, as there is no mechanism to allow government to make direct investment into the industrial sectors.

   The current options for industry which are needed to embrace scientific research at the nanoscale are:

- To finance their own R&D. The trend here is not encouraging as there is a shortage of skilled manpower within the U.S., and companies are under pressure to reduce overhead. The predictable result is either a reduction in the level of research or stretching the available R&D budgets by transferring operations to regions where talent and cost savings coincide.
- To either identify (a) a scientific discovery at a university that has a commercial fit and negotiate the IP rights or (b) establish piecemeal, a research program with a given university department. For industry, this is a time-consuming, arduous task and difficult to sustain; for the university, the time and specific nature of the investigation may conflict with current constraints-and-reward system within the academic community.
- To await academic business spin-offs financed by VCs to evolve to the point of proof-of-concept and engage in acquisition activity.

Relative to the process of direct government investment to industry, these routes extend the time needed for the commercialization of nanotechnology and put the development of U.S. nanotechnology-based international commerce at a disadvantage.

4. The last observation is that the U.S. is now fighting a war on two fronts. The obvious one is that against terrorism; the unstated one is the battle to dominate future nanotechnology-based industrial markets. The costs of the former are causing serious cuts in investment in the latter. As other nations competing with the U.S. are not burdened by this dilemma, our progress is again impeded. The long-term economic impact for the U.S. at this point in a new era of technology shift could be major and is probably being underestimated.

What can we do to improve our current situation?

We note that research and development do not earn money—they cost money—and that our nation's wealth and prosperity is ultimately driven by the level and added value of our exports to other countries. Our economic growth is heavily influenced by our manufacturing industry. Our options to improve the NNI program within the existing national constraints are very limited and must focus on using the basic academic research resources available to us to directly contribute to economic growth. We must create mechanisms to allow existing industrial sectors that are now involved in building nanotechnology-based economies to communicate their basic research needs to government. The dialogue should be structured to enable industry to directly support government in setting priority areas and in creating and maintaining science/technology roadmaps.

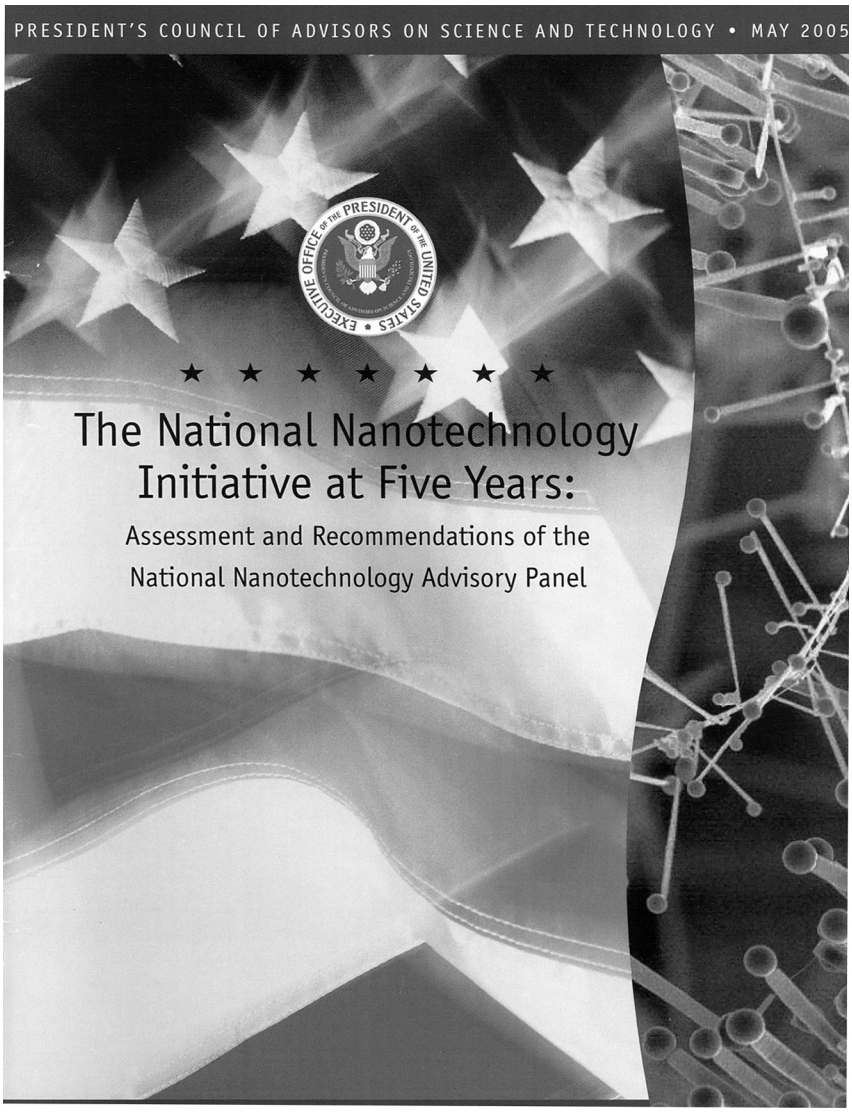
In short, if the government is opposed to direct investment in industry to promote economic growth, it must use its power and responsibility to focus the efforts of the academic research community to support U.S. industry in competing in the coming nanotech-based economy.

The government, through its funding agencies, would create the appropriate incentives and conditions for funding. These programs would not only have the intent of direct funding, but would also create an environment and the rewards to encourage academic research as a team effort (nanotechnology will need a multidisciplinary approach), establish clear performance guidelines (already a reality for industrial-based research), and a tangible result (science directed to economic benefit).

We perceive that the original National Nanotechnology Initiative was carefully phrased, as the word "technology" implies an end product and thus some social/economic benefit. The current reality is, however, that all the funding is directed to "nanoscience," and that while there is great promise of things to come, we have few new nanotechnology-based products in the public domain. This leads to a concern that, without more focus and evidence of progress, there could be either a public or political backlash that would be detrimental to U.S. commerce.

We urge the Committee to take every action within its power and sphere of influence to accelerate the transition from academically based science to commercially relevant technology.

We thank you for your attention.


PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY • MAY 2005
EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
The National Nanotechnology Initiative at Five Years:
Assessment and Recommendations of the National Nanotechnology Advisory Panel

About the President's Council of Advisors on Science and Technology

President Bush established the President's Council of Advisors on Science and Technology (PCAST) by Executive Order 13226 in September 2001. Under this Executive Order, PCAST "shall advise the President... on matters involving science and technology policy," and "shall assist the National Science and Technology Council (NSTC) in securing private sector involvement in its activities." The NSTC is a cabinet-level council that coordinates interagency research and development activities and science and technology policy making processes across Federal departments and agencies.

PCAST enables the President to receive advice from the private sector, including the academic community, on important issues relative to technology, scientific research, math and science education, and other topics of national concern. The PCAST-NSTC link provides a mechanism to enable the public-private exchange of ideas that inform the Federal science and technology policy making processes.

PCAST follows a tradition of Presidential advisory panels on science and technology dating back to Presidents Eisenhower and Truman. The Council's 23 members, appointed by the President, are drawn from industry, education, and research institutions, and other nongovernmental organizations. In addition, the Director of the Office of Science and Technology Policy serves as PCAST's Co-Chair.

About the National Nanotechnology Advisory Panel

The National Nanotechnology Advisory Panel (NNAP) was created by the United States Congress in the 21st Century Nanotechnology 21st Research and Development Act of 2003 (P.L. 108-153), signed by President Bush on December 3, 2003. The Act required the President to establish or designate a NNAP to review the Federal nanotechnology research and development program. On July 23, 2004, President Bush formally designated the PCAST to act as the NNAP.

About this Report

The Act that created the NNAP calls for this advisory body to conduct a review of the NNI and report its findings to the President. The Act calls upon the NNAP to assess the trends and developments in nanotechnology, and the strategic direction of the NNI, particularly as it relates to maintaining U.S. leadership in nanotechnology research. The Act also requires comment on NNI program activities, management, coordination, implementation, and whether the program is adequately addressing societal, ethical, legal, environmental, and workforce issues. The Act provides that the NNAP is to report on its assessments and to make recommendations for ways to improve the program at least every two years. The Director of the Office of Science and Technology Policy is to transmit a copy of the NNAP report to Congress. This is the first report of the NNAP under the Act.

Front cover: Zinc oxide nanorods with approximately 100-nm tin beads at tips. The properties of zinc oxide make these suitable for nanoscale, ultra-sensitive sensors. Courtesy of Prof. Zhong Lin Wang, Georgia Institute of Technology. Cover design by Nicolle Rager of Sayo-Art.

Copyright information: This document is a work of the U.S. Government and is in the public domain. Subject to the following stipulation, it may be distributed and copied. Copyrights to graphics included in this document are reserved by original copyright holders or their assignees, and are used here under the Government's license and by permission.

The National Nanotechnology Initiative at Five Years:

Assessment and Recommendations of the National Nanotechnology Advisory Panel

Submitted by the
President's Council of Advisors on Science and Technology
May 2005

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

May 16, 2005

President George W. Bush
The White House
Washington, D.C. 20502

Dear Mr. President:

We are pleased to transmit to you a copy of the report, *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, prepared by your Council of Advisors on Science and Technology (PCAST).

In response to direction in your FY 2004 Budget, PCAST initiated a review of the multi-agency National Nanotechnology Initiative (NNI). You subsequently signed Congressional legislation (P.L. 108-153) calling for an external National Nanotechnology Advisory Panel (NNAP), and in July 2004, by Executive Order, you formally designated PCAST as the NNAP.

The enclosed report represents PCAST's first assessment of the Federal government's nanotechnology-research efforts. PCAST undertook the legislatively required assessments in a manner that examined what we believe would be your four primary concerns:

1. **Where Do We Stand?**
2. **Is This Money Well Spent and the Program Well Managed?**
3. **Are We Addressing Societal Concerns and Potential Risks?**
4. **How Can We Do Better?**

We answer, in brief, that the United States holds a leadership position in nanotechnology but is being aggressively challenged by many nations. We find that the Federal investment to date has been money very well spent and that the NNI program has been well-managed - with societal concerns and risks to human health and the environment being wisely acknowledged and addressed. We recommend several improvements to the program, including the need for the NNI to increase coordination with the States as avenues of economic development and for program management to remain flexible in this fast-developing field.

The full PCAST discussed and approved this report at its public meeting on March 22, 2005. We appreciate the confidence you have placed in us by designating PCAST as the NNAP, and we look forward to continuing to monitor on your behalf the Federal programs engaged in this exciting field. Please let us know if you have any questions concerning the enclosed report.

Sincerely,

John H. Marburger, III
Co-Chair

E. Floyd Kvamme
Co-Chair

Enclosure

President's Council of Advisors on Science and Technology

CHAIRS

John H. Marburger, III, Ph.D.
Director, Office of Science Technology Policy

E. Floyd Kvamme
Partner, Kleiner Perkins Caufield & Byers

MEMBERS

Charles J. Arntzen, Ph.D.
Director, Arizona Biomedical Institute and The Florence Ely Nelson Presidential Chair, Department of Plant Biology, Arizona State University

Norman R. Augustine
Former Chairman and CEO, Lockheed Martin Corporation

Carol Bartz
Chairman of the Board, President, and CEO, Autodesk, Inc.

M. Kathleen Behrens, Ph.D.
Managing Director, RS Investments

Erich Bloch
Corporate R&D Management Consultant, The Washington Advisory Group

Stephen B. Burke
President, Comcast Cable Communications

G. Wayne Clough, Ph.D.
President, Georgia Institute of Technology

Michael S. Dell
Chairman and CEO, Dell Computer Corporation

Raul J. Fernandez
CEO, Dimension Data of North America

Marye Anne Fox, Ph.D.
Chancellor, North Carolina State University

Martha Gilliland, Ph.D.
Chancellor, University of Missouri-Kansas City

Ralph Gomory, Ph.D.
President, Alfred P. Sloan Foundation

Bernadine Healy, M.D.
Medical Senior Writer and Columnist for U.S. News and World Report; Former President of the American Red Cross; Former Director of NIH; Cleveland Clinic Foundation

Robert J. Herbold, Ph.D.
Retired Chief Operating Officer, Microsoft Corp.

Bobbie Kilberg
President, Northern Virginia Technology Council

Walter E. Massey, Ph.D.
President, Morehouse College

Gordon E. Moore, Ph.D.
Chairman Emeritus, Intel Corporation

E. Kenneth Nwabueze
CEO/CTO Corporation, SageMetrics

Steven G. Papermaster
Chairman, Powershift Ventures

Luis M. Proenza, Ph.D.
President, University of Akron

George Scalise
President, Semiconductor Industry Association

Charles M. Vest, Ph.D.
President, Massachusetts Institute of Technology

EXECUTIVE DIRECTOR

Stanley S. Sokul

OSTP STAFF LIAISON

Celia I. Merzbacher
Maureen O'Brien

Table of Contents

Executive Summary	1
Introduction and Background	5
CHAPTER 1: Where Do We Stand?	8
1. Nanotechnology R&D Investment	9
3. Research Output	14
3. Research Areas of Focus	17
4. Areas of Opportunity	19
5. Other Leadership Factors	22
6. Conclusions	23
CHAPTER 2: Is This Money Well Spent and the Program Well Managed?	24
1. NNI Strategic Plan and Management	24
2. NNI Accomplishments	33
3. Conclusions	34
CHAPTER 3: Are We Addressing Societal Concerns and Potential Risks?	35
1. Environmental, Health, and Safety	35
2. Education and Workforce Preparation	36
3. Ethical, Legal, and Other Societal Implications	38
4. Public Engagement	38
5. Conclusions	38
CHAPTER 4: How Can We Do Better?	39
1. Program Investment Areas and Funding Levels	39
2. Technology Transfer	39
3. Program Management	41
4. Societal Implications	42
5. Education/Workforce Preparation	43
6. NNAP Report Schedule	43
CHAPTER 5: Concluding Remarks and the NNAP's Future Areas of Focus	44
APPENDIX - NNI Program Component Areas	45
GLOSSARY	47
REFERENCES	49

List of Figures

Figure 1. Government Nanotechnology R&D Investments in 1997-2004 9
Figure 2. Number of Articles in ISI Web of Science Database Found by Searching "nano*" 14
Figure 3. Total Percentage of Articles in *Science, Nature,* and *Physical Review Letters* Identified by a Keyword Search on "nano*" 15
Figure 4. Number of Nanotechnology-related Patents Identified by a Search of Titles and Claims of Patents in the USPTO Database 17
Figure 5. Target Industries for Companies Involved with Nanotechnology in 2004 21
Figure 6. Organizations with a Role in the NNI and Their Relationships 31
Figure 7. NNI User Facilities and Research Centers 33

List of Tables

Table 1. Estimated Government Nanotechnology R&D Investments in 1997-2004 8
Table 2. Nanotechnology R&D Infrastructure Investments at State Level 11
Table 3. Focus Areas of Government Investments in Nanotechnology 18
Table 4. German Federal Funding by Priority Sector 19
Table 5. Relationships Between Program Component Areas and the Overarching NNI Goals 25
Table 6. Relationships Between Program Component Areas and NNI Agency Missions, Interests, and Needs 27

Executive Summary

The President's Fiscal Year (FY) 2004 Budget, released in February 2003, tasked the President's Council of Advisors on Science and Technology (PCAST) with reviewing the National Nanotechnology Initiative (NNI) and making recommendations for strengthening the program. Congress ratified the need for an outside advisory body with its passage of the 21st Century Nanotechnology Research and Development Act of 2003 (the Act), which called for the President to establish or designate a National Nanotechnology Advisory Panel (NNAP). By Executive Order, the President designated PCAST as the NNAP in July 2004. To augment its own expertise in managing large research and development (R&D) programs, PCAST identified a Technical Advisory Group (TAG) comprising about 45 nanotechnology experts representing diverse disciplines and sectors across academia and industry. The TAG is a knowledgeable resource, providing input and feedback with a more technical perspective.

The Act calls upon the NNAP to assess the NNI and to report on its assessments and make recommendations for ways to improve the program at least every two years. This is the first such periodic report provided by PCAST in its role as the NNAP.

The Administration has identified nanotechnology as one of its top R&D priorities. When FY 2005 concludes later this year, over 4 billion taxpayer dollars will have been spent since FY 2001 on nanotechnology R&D. In addition, the President's FY 2006 Budget includes over $1 billion for nanotechnology research across 11 Federal agencies. Such a substantial and sustained investment has been largely based on the expectation that advances in understanding and harnessing novel nanoscale properties will generate broad-ranging economic benefits for our Nation. As such, the NNAP members believe the President, the Congress, and the American people are seeking answers to four basic questions relative to the Federal investment in nanotechnology R&D:

1. ***Where Do We Stand?***
2. ***Is This Money Well Spent and the Program Well Managed?***
3. ***Are We Addressing Societal Concerns and Potential Risks?***
4. ***How Can We Do Better?***

Answers to these questions provide the assessments and recommendations called for by the Act. Our conclusions can be summarized as follows:

1. Where Do We Stand? Today, the United States is the acknowledged leader in nanotechnology R&D. The approximately $1 billion annual Federal Government funding for nanotechnology R&D is roughly one-quarter of the current global investment by all nations. Total annual U.S. R&D spending (Federal, State, and private) now stands at approximately $3 billion, one-third of the approximately $9 billion in total worldwide spending by the public and private sectors. In addition, the United States leads in the number of start-up companies based on nanotechnology, and in research output as measured by patents and publications. Our leadership position, however, is under increasing competitive pressure from other nations as they ramp up their own programs.

2. Is This Money Well Spent and the Program Well Managed? The NNAP members believe strongly that the money the United States is investing in nanotechnology is money very well spent, and that continued robust funding is important for the Nation's long-term economic well-being and national security. Nanotechnology holds tremendous potential for stimulating innovation and thereby enabling or maintaining U.S. leadership in industries that span all sectors. The focus of the NNI on expanding knowledge of nanoscale phenomena and on discovery of nanoscale and nanostructured materials, devices, and systems, along with building an infrastructure to support such studies, has been both appropriate and wise. The NNI has accomplished much already—advancing foundational knowledge, promoting technology transfer for commercial and public benefit, developing an infrastructure of user facilities and instrumentation, and taking steps to address societal concerns—and the economic payoffs over the long term are likely to be substantial.

The NNI appears well positioned to maintain United States leadership going forward, through both its coordinated interagency approach to planning and implementing the Federal R&D program and its efforts to interact with industry and the public. This approach is outlined clearly in the recently released NNI Strategic Plan, which spells out the goals and priorities for the initiative for the next 5 to 10 years. The NNAP members believe that this Plan provides an appropriate way to organize and manage the program.

3. Are We Addressing Societal Concerns and Potential Risks? The societal implications of nanotechnology—including environmental and health effects—must be taken into account simultaneously with the scientific advances being underwritten by the Federal Government. The NNI generally recognizes this, and is moving deliberately to identify, prioritize, and address such concerns.

Environmental, Health, and Safety. The NNAP convened a panel of experts from Government regulatory agencies, academia, and the private sector to discuss the environmental and health effects of nanotechnology. Based on these panel discussions, as well as on information received from the NSET Subcommittee and the TAG, the NNAP members believe that potential risks do exist and that the Government is directing appropriate attention and adequate resources to the research that will ensure the protection of the public and the environment. The NNAP members are particularly pleased that strong communication exists among the agencies that fund nanotechnology research and those responsible for regulatory decision-making.

Education. The future economic prosperity of the United States will depend on a workforce that both is large enough and has the necessary skills to meet the challenges posed by global competition. This will be especially important in enabling the United States to maintain its leadership role in nanotechnology and in the industries that will use it. The NNI has launched a range of education-related programs appropriate for classrooms at all levels and across the country, along with other programs that are aimed at the broader public. While the NNI cannot be expected to solve the Nation's science education problems single-handedly, the NNAP members believe that these NNI activities can help improve science education and attract more bright young minds into careers in science and engineering.

Other Societal Dimensions. Understanding the impact of a new technology on society is vital to ensuring that development takes place in a responsible manner. In addition to research into societal issues such as the environmental, health, and safety effects of nanotechnology, the NNI's diverse and growing R&D program is exploring other issues such as economic, workforce, and ethical impacts. In addition, communication among the various stakeholders and with the public on these topics is an important element of the program, as indicated by the establishment of an interagency subgroup to address this topic.

4. How Can We Do Better? The NNAP will monitor progress on the program elements discussed above; in the meantime, the NNAP offers the following recommendations aimed at further strengthening the NNI.

Technology Transfer. The level of interest and investment across many industrial sectors is growing and will likely outpace Government investment in the United States soon, if it hasn't already. The NNI needs to take further steps to communicate and establish links to U.S. industry to further facilitate technology transfer from the lab to the marketplace. The NNAP calls attention to two areas that would augment the existing suite of activities and enhance commercialization of research results.

- **The NNI's outreach to, and coordination with, the States should be increased.** Such efforts would complement those NNI activities already underway with various industrial sectors. The States perform a vital role in fostering economic development through business assistance programs, tax incentives, and other means. In addition, collectively the States are spending substantial amounts in support of nanotechnology R&D and commercialization. The NNAP members believe that practical application of NNI-funded research results, workforce development, and other national benefits will increase with improved Federal-State coordination.

- **The NNI should examine how to improve knowledge management of NNI assets.** This would include assets such as user facilities and instrumentation available to outside researchers, research results, and derivative intellectual property. Through mechanisms such as publicly available and searchable databases, the NNI can—and should—improve infrastructure utilization and the transfer of technology to the private sector.

The NNAP notes that, although ultimate commercialization of nanotechnology is desirable and to be supported, the NNI must remain mindful that its primary focus is on developing an understanding of the novel properties that occur at the nanoscale and the ability to control matter at the atomic and molecular level. While we all want the United States to benefit economically from nanotechnology as quickly as possible, it is critically important that the basic intellectual property surrounding nanotechnology be generated and reside within this country. Those who hold this knowledge will "own" commercialization in the future.

Environmental and Health Implications. The NNI should continue its efforts to understand the possible toxicological effects of nanotechnology and, where harmful human or environmental effects are proven, appropriate regulatory mechanisms should be utilized by the pertinent Federal agencies. Nanotechnology products should not be immune from regulation, but such regulation must be rational and based on science, not perceived fears. Although it appears that the public and the environment are adequately protected through existing regulatory authorities, the NNAP encourages the Government regulatory agencies to work together to ensure that any regulatory policies that are developed are based on the best available science and are consistent among the agencies.

The NNAP notes that research on the environmental and health implications of nanomaterials and associated products should be coordinated not only within the Federal Government, but with other nations and groups around the world to ensure that efforts are not duplicated unnecessarily and information is shared widely.

Education/Workforce Preparation. A key to realizing the economic benefits of nanotechnology will be the establishment of an infrastructure capable of educating and training an adequate number of researchers, teachers, and technical workers. To maximize the value of its investment in developing materials and programs for education and worker training, the NNI should establish relationships with the Departments of Education and Labor. While the science agencies such as the National Science Foundation (NSF) can conduct education research and design excellent programs and materials, ultimately the mission agencies, Education and Labor, must be engaged to disseminate these programs and materials as widely as possible throughout the Nation's education and training systems.

The NNI's education focus should be on promoting science fundamentals at K-16 levels, while encouraging the development and incorporation of nanotechnology-related material into science and engineering education. To promote mid-career training for professionals, the NNI should partner with and support professional societies and trade associations that have continuing education as a mission.

Societal Implications. The NNI must support research aimed at understanding the societal (including ethical, economic, and legal) implications and must actively work to inform the public about nanotechnology. Now more than ever, those who are developing new scientific knowledge and technologies must be aware of the impact their efforts may have on society.

In summary, the NNAP supports the NNI's high-level vision and goals, and the investment strategy by which those are to be achieved. Panel members feel that the program can be strengthened by extending its interaction with industry, State and regional economic developers, the Departments of Education and Labor, and internationally, where appropriate. The NNI should also continue to confront the various societal issues in an open, straightforward, and science-based manner.

Introduction and Background

"Nanotechnology" touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. Like information technology, nanotechnology has the potential to impact virtually every industry, from aerospace and energy to healthcare and agriculture. Based on the ability to see, measure, and manipulate matter at the scale of atoms and molecules, nanotechnology was born, in many ways, with the advent of atomic force microscopy in the mid-1980s. Today many industries such as semiconductors and chemicals already are creating products with enhanced performance based on components and materials with nanosized features.

The breathtaking possibilities for useful and powerful nanotechnology applications led to the formal establishment of a National Nanotechnology Initiative (NNI) in Fiscal Year (FY) 2001. Due to its potential to promote innovation and economic benefits, as well as to strengthen the position of the United States as a leader in science and technology, the Administration has identified nanotechnology as a top research and development (R&D) priority for the past several years. Since its inception in FY 2001, the NNI budget has more than doubled and the number of participating agencies has grown from 6 to over 20.

Such a broadly distributed program demands strong interagency coordination, which is provided by a subgroup of the National Science and Technology Council (NSTC), the Cabinet-level body by which the President coordinates science and technology policies across the Federal Government. Within the NSTC Committee on Technology, the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee is responsible for coordinating, planning, implementing, and reviewing the NNI.

The history of the President's Council of Advisors on Science and Technology (PCAST) involvement with the NNI extends back to 1999 when the analogous body under the previous Administration supported the proposal for establishing such an initiative. In a letter to the President, that body included a recommendation that "the progress toward NNI goals be monitored annually by an appropriate external body of experts, such as the National Research Council." In part based on this recommendation, the National Research Council was commissioned to do a study of the NNI, which was released in 2002 (NRC 2002). The first of that study's ten recommendations was that the Office of Science and Technology Policy establish an independent standing nanoscience and nanotechnology advisory board to provide advice to the NSET Subcommittee on policy, strategy, goals, and management.

The President's FY 2004 Budget, released in February 2003, acknowledged the National Research Council's recommendation for external review, and directed PCAST to conduct an assessment and provide advice regarding the strategic direction of the NNI program. PCAST began this task shortly thereafter.
The requirement for an ongoing outside advisory panel was ratified by Congress in the 21st Century Nanotechnology Research and Development Act of 2003, Public Law 108-153 (the Act), which called for the President to establish or designate a National Nanotechnology Advisory Panel (NNAP). PCAST's role was reaffirmed when, in July 2004 by Executive Order, the President formally designated PCAST to fulfill the duties of the NNAP (Bush 2004). The order amended the original Executive Order (Bush 2001) that commissioned PCAST, thus establishing that nanotechnology should be included in the formal PCAST charter.

The Act calls upon the NNAP to assess the NNI in the following areas:

- Trends and developments in nanotechnology
- Progress in implementing the program
- The need to revise the program
- Balance among the component areas of the program, including funding levels
- Whether program component areas, priorities, and technical goals developed by the NSET Subcommittee are helping to maintain U.S. leadership
- Management, coordination, implementation, and activities of the program
- Whether social, ethical, legal, environmental, and workforce concerns are adequately addressed by the program

The Act requires the NNAP to report on its assessments and to make recommendations for ways to improve the program at least every two years. This is the first such report provided by PCAST in its role as the NNAP. (Hereafter, "NNAP" is used to refer to PCAST in its capacity as the panel called for by the Act.)

To augment its own expertise in managing large R&D programs, the NNAP identified a Technical Advisory Group (TAG) comprising approximately 45 nanotechnology experts who represent diverse disciplines and sectors across academia and industry. The TAG is a knowledgeable resource, providing input and feedback with a more nanotechnology-specific technical perspective.

In the course of performing its assessment, the NNAP convened panels of experts to discuss advancements and opportunities in science and technology as well as the potential environmental, health, and safety implications of nanotechnology. The NNAP also met with members of the NSET Subcommittee throughout the review process to discuss the NNI R&D programs and thereby understand how the initiative is organized and managed. In addition to these sources, the NNAP called upon its TAG on several occasions for broader expert opinions on various topics. Members of the NNAP attended a number of the workshops organized by the NNI over the past two years, including the Research Directions II Workshop held in September 2004, to gain a better understanding of the broad research and application opportunities. These activities, along with numerous informal interactions by NNAP members with a range of nanotechnology stakeholders around the country and worldwide, have provided the basis for this report.

Including the more than $1 billion that the Federal Government estimates it will spend in FY 2005, over 4 billion taxpayer dollars have been spent since FY 2001 on nanotechnology R&D. In addition, the President's 2006 Budget includes over $1 billion for research across 11 Federal agencies (including both NIH and the National Institute for Occupational Safety and Health, or NIOSH, within the Department of Health and Human Services). With such a large and sustained investment, the NNAP members believe the President, the Congress and the American people are seeking answers to four basic questions relative to the Federal investment in nanotechnology R&D:

1. ***Where Do We Stand?***
2. ***Is This Money Well Spent and the Program Well Managed?***
3. ***Are We Addressing Societal Concerns and Potential Risks?***
4. ***How Can We Do Better?***

These questions provide the underlying structure for this report, and the answers provide the assessments and recommendations called for by the Act.

As the first of what will be periodic assessments, this report focuses especially on the question of U.S. competitiveness. The Nation cannot afford to cede leadership in this emerging area of science and technology. Remaining at the forefront in nanotechnology requires not only sustained investment and public-private cooperation, but also an understanding of where the opportunities lie, and of the level and direction of activity in other nations.

Definition of Nanotechnology

Since its inception, the NNI has defined "nanotechnology" as encompassing the science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1 to 100 nanometers. However, nanotechnology is not merely working with matter at the nanoscale, but also research and development of materials, devices, and systems that have novel properties and functions due to their nanoscale dimensions or components.

Wisely in our view, the NNI has distinguished nanotechnology R&D from other types of ongoing scientific research that have achieved a certain level of miniaturization or that operate at a nanometer-length scale. One area in which this distinction is especially challenging is at the intersection of nanotechnology and biology. Many biological structures and processes are on the nanoscale. The National Institutes of Health (NIH) have the following corollary:

> *While much of biology is grounded in nanoscale phenomena, NIH has not re-classified most of its basic research portfolio as nanotechnology. Only those studies that use nanotechnology tools and concepts to study biology; that propose to engineer biological molecules toward functions very different from those they have in nature; or that manipulate biological systems by methods more precise than can be done by using molecular biological, synthetic chemical, or biochemical approaches that have been used for years in the biology research community are classified as nanotechnology projects.*

The NNAP endorses this definitional focus upon the novel properties that occur at the nanoscale and the distinction made between nanotechnology and biology, and the associated goal of understanding and gaining control over them.

CHAPTER 1: Where Do We Stand?

Following the establishment of the NNI in FY 2001, worldwide interest and investment in nanotechnology R&D have grown steadily. Today, virtually every country that supports scientific and technology R&D has a nanotechnology initiative; by many estimates, the total investment by governments outside the United States surpasses $3 billion annually, with comparable investment by the private sector.

While technical and business experts continue to debate the future advancements and economic impacts of nanotechnology, public interest and media coverage have grown dramatically. Scientific advances and technical progress continue, spurred on by vast investments by governments and the private sector, yet most agree that nanotechnology is, by and large, still in a nascent stage and that its ultimate impact on the world economy remains to be seen. What all agree upon is that significant potential clearly exists.

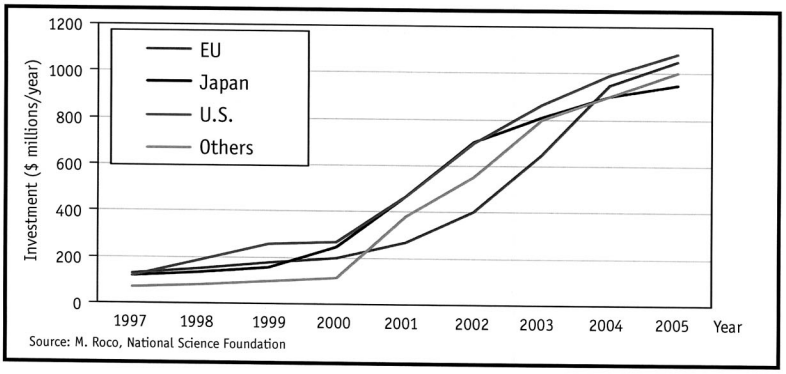
The question, "Where Do We Stand?" refers to the basic competitive position of the United States relative to other countries in the nanotechnology arena. Because nanotechnology is still at an early stage and is dominated by both publicly and privately supported R&D activities, a determination of the Nation's competitive position depends on benchmarking research rather than on economic indicators such as market share. The measurement of research outputs is notoriously challenging (Committee on Science, Engineering, and Public Policy 2000); frequently used metrics include the numbers of and citations to scientific and technical publications and patents. Because some of the knowledge created through research is not captured by these measures of output, the amount going into the pipeline in the form of financial support often is used as an indicator of research activity level, and presumably correlates to some degree with the generation of new knowledge. The NNAP therefore has chosen to compare nanotechnology R&D investment, as well as publication and patent output, as a means of assessing the position of the United States in this emerging area.

Table 1.
Estimated Government Nanotechnology R&D Investments in 1997-2004 ($ Millions)

Region	1997	1998	1999	2000	2001	2002	2003	2004	2005
EU	126	151	179	200	~ 225	~ 400	~ 650	~ 950	~ 1,050
Japan	120	135	157	245	~ 465	~ 720	~ 800	~ 900	~ 950
U.S.	116	190	255	270	465	697	862	989	1,081
Others	70	83	96	110	~ 380	~ 550	~ 800	~ 900	~ 1,000
Total	**432**	**559**	**687**	**825**	**~ 1,535**	**~ 2,350**	**~ 3,100**	**~ 3,700**	**~ 4,100**
(% of 1997)	(100%)	(129%)	(159%)	(191%)	(355%)	(547%)	(720%)	(866%)	(945%)

Source: M. Roco, National Science Foundation

Figure 1.
Government Nanotechnology R&D Investments in 1997-2004



Source: M. Roco, National Science Foundation

1. Nanotechnology R&D Investment

Nanotechnology R&D spending is distributed among governments (including national, regional, State, and local), universities, corporations, and venture capital investors. The availability and consistency of accurate figures varies for the different categories. When comparing the data available for various countries, difficulties may arise due to differences in the definition of nanotechnology, the inclusion of private contributions or other variations in the calculation of government funding, difficulty in getting some private—especially venture capital—investment data, mismatch in investment periods, and the various exchange rates employed. Rather than attempt to normalize disparate data sets, the NNAP has chosen to review a sampling of available data and to identify common trends.

1A. International Government Spending

While sources vary regarding international levels of nanotechnology R&D investment, one thing that all the data sets agree upon is that nanotechnology spending has been steadily increasing, reaching record levels in 2005. For the purpose of illustration, Table 1 and Figure 1 show one set of estimates indicating that national investments in nanotechnology worldwide increased over eightfold during the period from 1997 to 2005. Investment estimates shown in Table 1 are made using the nanotechnology definition of the NNI (this definition does not include microelectromechanical systems [MEMS], microelectronics, or general research on materials).

Other estimates vary from the amounts shown in Table 1. A report by the European Commission (EC) (2004) estimates that total worldwide government spending in 2003 was just over $3.5 billion, including funding by U.S. States (in addition to Federal programs) and by original European Union (EU) members and associated and acceding European countries.

In a more recent report, Lux Research (2004) estimated that worldwide government spending on nanotechnology research reached $4.6 billion in 2004: approximately 35% ($1.6 billion) was by governments in North America; another 35% ($1.6 billion) was by Asian governments; 28% ($1.3 billion) was by European governments, including the EC; and 3% ($133 million) was by all other governments. The Lux Research data include U.S. State funding in the total for North America and incorporate figures from associated and acceding EU countries in the European estimate.

As previously stated, available figures do not always allow for an "apples to apples" comparison, even among Federal Government expenditures. For instance, some countries invest in research through a combination of Government and corporate contributions. There is often inconsistency in the definition of nanotechnology for purposes of counting R&D expenditures. For example, some countries may include MEMS or biotechnology funding that is not counted under the strict U.S. definition of nanotechnology. Another variable between countries is the treatment of salaries for researchers. Whereas, U.S. figures include a salary component (e.g., as a portion of research grants and for Federal laboratory employees), many other countries fund salaries out of separate accounts from those reported as "nanotechnology R&D."

Although direct comparisons are difficult, the data collectively show that many countries are making significant public investments in nanotechnology R&D, and that these investments have increased sharply since 2000. The similar levels in the investments by the United States, Europe, and Japan, as shown in Figure 1, suggest an element of competition among these leaders. Because the NNAP members believe it is important for the United States to understand how its Federal investments stack up against public investment by other countries, the Panel has commissioned the Science and Technology Policy Institute (STPI), a Federally Funded Research and Development Center (FFRDC) that provides technical research and analysis to the Federal Government, to do a more detailed study to assess U.S. funding as it compares to other governments, including developing a means for normalizing and comparing international government investments.

1B. Regional, State and Local Spending

One difficulty in comparing U.S. Government spending to foreign government spending is that the contributions of U.S. State and local governments (and their foreign counterparts, where they exist) are often overlooked. A fair assessment of the overall U.S. competitive position must therefore include the significant contributions of U.S. State and local governments.

Regional, State, and local initiatives provide a vehicle for additional R&D funding, and a vital avenue for commercialization and economic development activity. In fact, State and local governments typically develop initiatives and commit funding precisely for the expected local economic development benefits this investment will yield. Lux Research reports that in 2004 U.S. State and local governments invested more than $400 million into nanotechnology research, facilities, and business incubation programs (Lux Research, Inc. 2005). Funding provided by State governments is often augmented, or leveraged, by additional resources provided through partnership with local private sector interests, universities, Federal Government agencies, and/or other interested regional organizations. These partnerships typically seek to build on existing regional competencies (e.g., a local research institution, a Government laboratory, and/or a strong local high-technology business community). A partial list of State investments in R&D infrastructure, typically at universities, is shown in Table 2.

In addition to supporting university-based infrastructure, many regional, State, and local initiatives support the development of a technically skilled workforce through the creation or promotion of education and training opportunities. Some have done this by leveraging existing Federal programs (e.g., NSF's Nanotechnology Undergraduate Education and Research Experience for Undergraduates programs) or through the establishment of new programs, such as providing nanotechnology-relevant curriculum assistance to community colleges. Another function of many regional initiatives is to facilitate partner access to NNI user facilities as well as to other nanotechnology resources and business expertise.

Table 2.
Nanotechnology R&D Infrastructure Investments at State Level

State	Recipient	Description	Partnership Model
AZ	Nano-bio research center	Research Infrastructure	University-State
CA	California Nanosystems Institute	Building Infrastructure	Metropolitan-State
FL	Center at University of South Florida	Faculty Recruitment & Infrastructure	University-State
GA	Center at Georgia Tech.	Building & Research Infrastructure	
IL	Nanoscience Centers (Northeastern Univ., U. of IL, Argonne National Laboratory)	Building & Research Infrastructure	Non-profit-Metropolitan-Regional
IN	Nanotechnology Center at Purdue	Building Infrastructure	
NJ	Support at NJ Institute of Tech. and photonics consortium	Building Infrastructure	State-Industry
NY	Nanoelectronics Center, Albany	Building & Research Infrastructure	University-State
OK	NanoNet	EPSCoR	University-Region
OR	ONAMI – Oregon Nano-Micro Interface Institute	Research Infrastructure	University-Industry
PA	Nanotechnology Center		Non-profit-University-State
SC	NanoCenter	Building Infrastructure	
SD	Center for Accelerated Applications at the Nanoscale	Research Infrastructure	UniMversity-State
VA	Various institutions and Luna Innovations	Research Matching & Infrastructure	University-State
WA	University of Washington, Washington Tech. Center	Clean Room Maintenance	University-State Partnership

Source: NSTC Report of the NNI Workshop on Regional, State and Local Initiatives in Nanotechnology, September 30-October 1, 2003 (2005). Note: The examples offered here provide a sampling of infrastructure investments by various U.S. States. This list is not comprehensive and does not include non-infrastructure investments.

Defining the Nanotechnology "Industry"

Attempts to define the nanotechnology "industry" inevitably result in definitions that are either too narrow or too broad.

If the definition were limited to that part of industry in which the nanotechnology aspect is dominant—that is, to companies that deliver pure nanotechnology—then it would only capture highly specialized activities such as the manufacture and sale of carbon nanotubes. Under this narrow definition the industry appears extremely small, and is likely to remain so for some time. The definition could be broadened somewhat by including the manufacture and sale of instruments that are necessary for measuring and manipulating matter at the nanoscale, because these sales are nanotechnology dependent. Even this expanded definition, however, continues to suggest a very small industry.

Taking a broader economic view, it is noteworthy that a wide variety of industries—including electronics, cosmetics, textiles, and pharmaceuticals—already use nanotechnology to make existing products better. Nanotechnology is used to produce stain-free khakis, transparent zinc-oxide-based sunblock, scratch-resistant automobile paint, more powerful semiconductors, and many other products. Under this further expanded 'count-any-contribution' definition, the nanotechnology industry is already quite large, and likely to grow to an enormous scale. Because nanotechnology does not dominate these products, however, this definition arguably over-counts the actual contribution of nanotechnology to the economy. Nonetheless, nanotechnology does contribute to the performance of these products and, in many cases, makes the performance possible in the first place.

Ultimately, nanotechnology is expected to be embedded throughout our economy, its contributions ranging from barely detectable to wholly dominant. Any credible attempt to define a nanotechnology "industry," therefore, will have to establish a threshold contribution level and explain why that level was chosen. This report does not attempt to choose or defend such a threshold.

While much activity is taking place to organize and secure support for regional nanotechnology initiatives from State and local governments and the private sector, the ultimate economic development success of most of these ventures remains to be seen. To the extent that nanotechnology parallels the biotechnology industry, regional "cluster" development may prove an excellent model for equipping local communities with competitive advantages. Technology-based cluster development builds upon a foundation of critical components for economic success—research expertise and infrastructure, technical and management talent, risk capital, commercial infrastructure, and an entrepreneurial culture. Certainly, this type of activity should be encouraged and its progress monitored to determine which of the arrangements ultimately yield long-term economic development and growth.

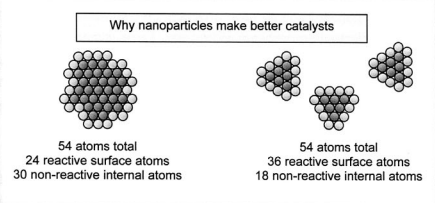
A workshop held in the Fall of 2003 brought together representatives from regional, State, and local nanotechnology initiatives across the country to share information and experiences. The resulting report (NSTC 2005), to be released soon, will serve as a useful primer for those who are at the early stages of launching similar activities. The NNAP strongly encourages the NNI to continue to interact with those regional, State, and local initiatives to assist their progress and to seek additional channels by which technology transfer may take place.

Nanomaterials for Clean Energy

Nanotechnology is helping to clean our air through better-performing and cheaper catalysts. By controlling the size and composition of platinum-based catalytic materials, the number of active sites can be dramatically increased, leading to improved catalytic converters that reduce auto emissions and help control pollution from power plants or stationary industrial sources. In today's converters, much of the platinum, which makes up roughly two-thirds of the total cost of the converter, is buried inside relatively coarse metal particles where it is unable to react with pollutants.

Researchers at Stanford University (supported by NSF and DOE) and NASA Ames Research Center developed new concepts for computationally modeling nanomaterials. In 2003, Nanostellar, Inc. was formed to develop the concepts into technologies for designing and fabricating controlled nanomaterials with optimized properties for catalytic reactions. Nanostellar has dramatically reduced the amount of platinum required for automotive emission control by designing and producing nanoparticles that combine the precious metal with other less costly metals. In addition to lowering cost, converters based on nanocomposite catalysts outperform traditional products, particularly at "cold start" where most gasoline and diesel engine pollution is generated.

Nanotechnology's contributions to pollution control may just be beginning. In a separate study, researchers at Brookhaven National Laboratory have shown that platinum mixed with iridium in single atomic layers is more than 20 times more active on a per atom basis than commercial catalysts.



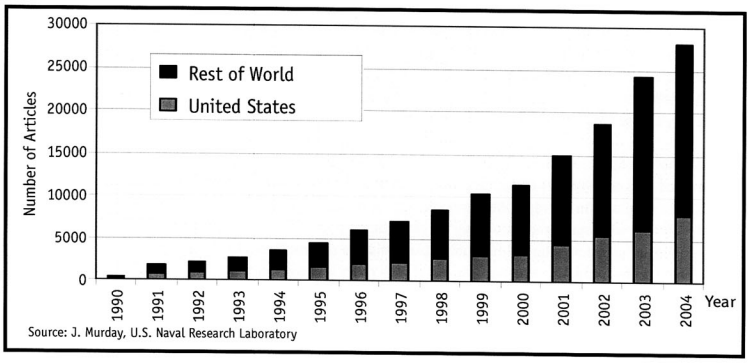
In addition to finding use in pollution control devices, nanostructured catalysts can improve the efficiency and reduce the cost of conventional and next-generation technologies for energy production and storage (e.g., in fuel cells, coal gasification, and improved photovoltaic cells).

1C. Private Investment

Measures of private investment include both corporate internal investment and venture capital activity. Obtaining firm data in this area is difficult, because private corporations and investors often consider such information to be proprietary. However, in 2003 the European Commission estimated worldwide private R&D funding to be close to 2 billion Euros (Commission of the European Communities 2004).

Of the $8.6 billion that Lux Research estimates was spent on nanotechnology R&D worldwide in 2004, $3.8 billion was by corporations: 46% ($1.7 billion) was by North American companies, predominantly in the United States; 36% (1.4 billion) was by Asian companies; 17% ($650 million) by European firms; and less than 1% ($40 million) was by businesses in other regions. Additional private sector investments were made by venture capital firms investing in nanotechnology start-up companies. These investments totaled roughly $400 million in 2004 (Lux Research Inc. 2004).

Figure 2.
Number of Articles in ISI Web of Science Database Found by Searching "nano*"



Because nanotechnology is a relatively new area, the "industry" is evolving rapidly. A study by EmTech Research (2005) identified approximately 600 companies based in the United States or with significant U.S. operations that are engaged in nanotechnology R&D, manufacture, sale, and use. Of these nearly three-quarters (72.9%) were founded in the past 10 years. A significant percentage of those companies (57.6%) have products on the market, although business plans based on development and licensing of intellectual property are widespread. Large companies typically are focusing more on applications and many have early stage R&D subsidiaries and/or research collaborations with small businesses or start-ups. Members of the NNAP observe a similarity between nanotechnology and the biotechnology industry in the 1980s and 1990s, suggesting that future acquisitions and consolidations are likely.

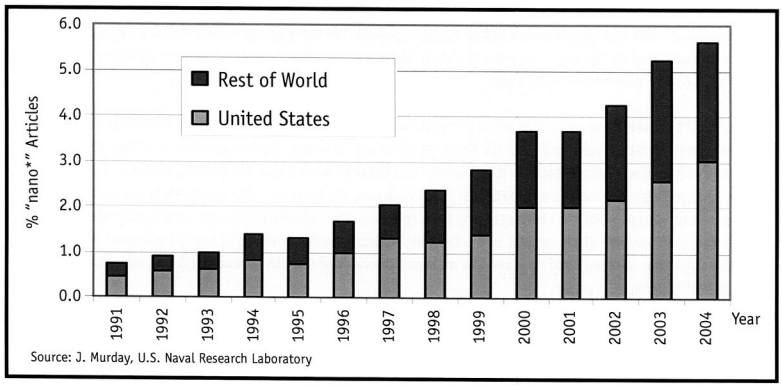
2. Research Output

In addition to judging United States competitiveness by comparing investments worldwide, the NNAP sought to compare research output. However, it is important to keep in mind that patents and publications are based on research that was performed one or more years prior to submission, with additional time elapsed between the submission of the research and its publication. Just as research spending precedes discovery and innovation, these measures lag behind.

2A. Publication Output

One metric often used to gauge scientific leadership is the number of peer-reviewed scientific articles. Figure 2 shows the results of a search of one of the principal databases of scientific literature, the Institute for Scientific Information (ISI) Web of Science a searchable database of about 5400 professional journals, using the keyword "nano*." The chart shows an escalation in the total number of publications since 1989, and especially since 2000. Although the number of publications from the United States has grown throughout the period, the percentage of publications originating from the United States has declined from approximately 40% in the early 1990s to less than 30% in 2004. In a similar study, Zucker and Darby (2005) show that the United States is dominant in terms of the number of nanotechnology research articles published, accounting for more than twice the number published by the country with the next-highest number, China. However, Zucker and Darby also note that the U.S. share is decreasing. They summarize: "Taken as a whole these data confirm that the strength and depth of the American science base points to the United States being the dominant player in nanotechnology for some time to come, while the United States also faces significant and increasing international competition."

Figure 3.
Total Percentage of Articles in *Science, Nature,* and *Physical Review Letters* Identified by a Keyword Search on "nano*"



Whereas the total number of publications is an indicator of the quantity of research output, a better indicator of the *quality* of the output is represented by publication in the most highly regarded and widely read scientific journals. A search of three high impact journals, *Science, Nature, and Physical Review Letters*, shows a 100% increase in the percentage of articles related to nanotechnology in these journals. Among these publications, the United States has produced an even larger fraction—over 50%—of the nanotechnology-related articles (Figure 3). These data show, however, as did those from the broader selection of publications, that there is a steady increase in the percentage that originates from other countries.

2B. Patent Output

Another metric commonly used to gauge leadership in technology innovation, and one that is perhaps more indicative of movement toward a commercial application, is the number of patents and patent applications. A study by Huang et al. (2004) reveals the rapid growth of nanotechnology-related patents. Based on a search of the full text of patents in the U.S. Patent and Trademark Office (USPTO) database using a list of nanotechnology-related keywords, over 8,600 nanotechnology-related patents were issued in 2003, an increase of about 50% over the number issued in 2000. The analysis pointed to strong U.S. leadership in the number of patents issued. U.S. entities accounted for over 60% of nanotechnology patents recorded in the USPTO database during the years 1976 to 2003. In addition, among the patents identified by the study, U.S. patents received the most citations by subsequently filed patents, another indication of technology leadership. Overall, the five countries receiving the highest number of nanotechnology-related patents in 2003 were the U.S. (5,228), Japan (926), Germany (684), Canada (244) and France (183). The number of nanotechnology-related patents issued by the USPTO to assignees in other countries, especially the Netherlands, Korea, Ireland, and China, is likewise increasing.

Because a full-text search finds patents that mention nanotechnology-related terms in the background section of the patent, even though the patented invention itself does not necessarily meet the definition of nanotechnology, Huang et al. also performed a search of just the patent title and claims. The results of this search for the years between 1990 and 2003 (shown in Figure 4) show trends that are similar to those indicated by the broader full-text search.

Nanocrystalline Synthetic Bone is Stronger and Heals Faster

Every year, orthopedic surgeons will implant medical devices into millions of Americans to mend broken bones, repair ligaments and tendons, and relieve pain in backs, hips and knees. However, even the best materials and devices used today for such procedures are a compromise. Metal screws and pins can loosen or permanently weaken the surrounding bone while ordinary fillers or cements can be very slow to—or may never—fully heal.

About half the weight of natural bone is the mineral hydroxyapatite, which makes a synthetic version of the mineral an obvious candidate for bone repair or replacement. Hydroxyapatite is in fact highly biocompatible. Bone cells attach to it and grow, and thereby encourage the healing process. But when manufactured using conventional methods, it forms a ceramic material with relatively large crystals compared to those in bones. The larger crystal size makes the synthetic material structurally weaker and less biocompatible than natural bone. Ceramic hydroxyapatite is made of many individual crystals packed together, and one way to make the material stronger and more biocompatible is by reducing the size of individual crystals.

Research performed at MIT, and supported in part by the Office of Naval Research, has led to a technique for producing very pure, dense hydroxyapatite with crystals that are less than 100 nanometers across, similar to the size of hydroxyapatite crystals found in natural bone. This synthetic bone nanomaterial more closely matches the strength of natural bone and, when used to fill voids caused by injury or disease, allows bones to heal faster and more completely than when coarser hydroxyapatite is used.

In 2001, Angstrom Medica was founded to develop structural synthetic bone nanomaterials for medical use. Since then, the company has received several SBIR grants from the National Science Foundation and the National Institutes of Health and raised nearly $4 million in venture capital. In February 2005, Angstrom Medica received FDA approval to market its material for use as a bone void filler, making it the first engineered nanomaterial specifically cleared by FDA for medical use.

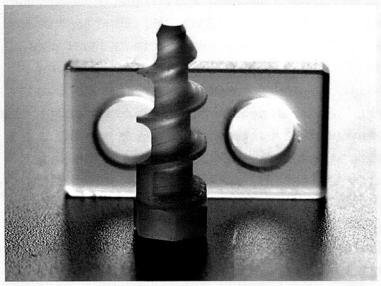
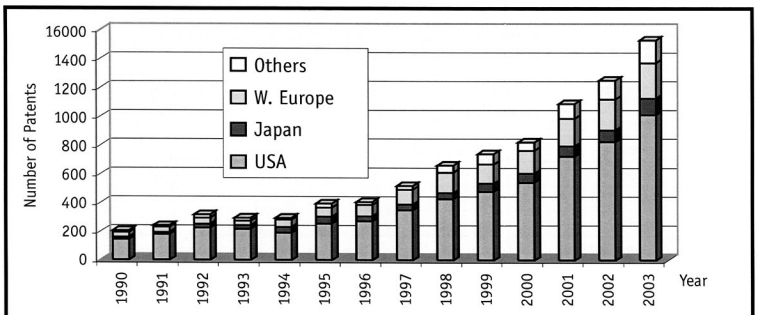


Photo courtesy of Angstrom Medica

Angstrom Medica plans to take advantage of the mechanical strength of its dense, nanocrystalline hydroxyapatite to make orthopedic pins and screws (see photo) for applications like anchoring repaired ligaments, fusing spinal vertebrae, or pinning broken bones. Unlike metal screws, nanocrystalline hydroxyapatite implants should integrate fully with the natural bone, leaving it as good as new. And, as a side benefit, they won't set off the metal detectors at the airport!

Figure 4.
Number of Nanotechnology-related Patents Identified by a Search of Titles and Claims of Patents in the USPTO Database



Source: Huang, Z., H. Chen, Z.-K. Chen, and M. Roco. 2004. *International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis based on USPTO Patent Database. Journal of Nanoparticle Research,* 6:325-354.

3. Research Areas of Focus

The preceding sections indicate that the United States has a leadership position in terms of total investment, research publications, and patents related to nanotechnology. In addition to these overall measures, an accurate assessment of U.S. competitiveness requires the identification of countries that have adopted a strategy of making targeted investments, thereby positioning themselves to be leaders in a key industry or platform technology.

3A. Broad International Survey

In June 2004, NSF sponsored an international meeting on responsible nanotechnology research and development at which 25 countries and the European Union were represented. Attendees were asked to provide estimates of government funding and areas of particular research interest. Results of this survey indicated that some nations have broad research programs, like the United States, whereas others have opted to make targeted research investments. Table 3 shows the key areas in which various countries are focusing their nanotechnology efforts according to the survey responses. These countries appear to be investing especially in materials/manufacturing, biotechnology, and electronics.

3B. Asia

According to reports from the Asian Technology Information Program (ATIP), which tracks activity among Asian Pacific nations, China is especially strong in nanomaterials development. China's nanomaterials research focus, its low cost of doing business, its talented labor pool, and its potentially large domestic market, could provide incentive for further investment by foreign corporations seeking to capitalize on nanomaterials development (ATIP 2003; ATIP 2004). Other Asian countries are likewise focusing nanotechnology research efforts on industries in which they already hold a comparative advantage. According to ATIP, Korea is focusing on nanoelectronics with strong industry participation, Taiwan is targeting nanoelectronics, and Singapore has a particular emphasis on nanobiotechnology. Taiwan's National Science Council, which administers government funding for Taiwan's nanotechnology effort, plans to establish three technology research parks;

Table 3.
Focus Areas of Government Investments in Nanotechnology

Country	Materials/ Manufact.	Devices (including Electronics & Optics)	Energy & Environment	Biotech/ Medical	Instrument Development	Education
Argentina	X					
Australia	X	X	X	X		
Austria						
Belgium	X	X		X		
Brazil	X	X		X		
Taiwan	X	X		X		
Czech Republic	X	X		X		
European Union*	X	X	X	X	X	X
France	X			X		
Germany	X	X		X	X	
India	X	X		X	X	X
Ireland	X	X	X	X		
Israel	X			X		
Italy	X	X		X	X	
Japan	X	X	X	X	X	
Korea	X	X				
Mexico	X					
Netherlands	X	X		X	X	
New Zealand	X					
Romania	X			X		
South Africa	X		X	X		
Switzerland	X	X		X	X	
United Kingdom	X	X		X		
United States	X	X	X	X	X	X

Source: June 2004 International Dialogue on Responsible Research and Development of Nanotechnology, http://www.nanoandthepoor.org/international.php

Note *: While the EU as a whole is pursuing a broad program, individual EU countries (also shown here) have more targeted areas of research.

two would focus on nanoelectronics research. Though Japan has the strongest government support for nanotechnology research in the region, with broad scope, its recognized strength is in infrastructure and instrumentation. Japan also is focused particularly on the commercialization of nanotechnology; recently a number of new initiatives were launched to assist Japanese businesses and to develop strategies aimed at creating new nanotechnology-related industries. As part of a larger S&T strategy, the Japanese government has included the "development of new devices using nanotechnology" as one of five "leading projects" aimed at revitalizing the Japanese economy.

Table 4.
German Federal Funding by Priority Sector (in Millions of Euros)

	2002	2003	2004	2005
Nanoelectronics	19.9	25.0	44.7	46.2
Nanomaterials	19.2	20.3	32.7	38.1
Optical Science & Engineering	18.5	25.2	26.0	26.0
Microsystems Eng	7.0	7.0	9.4	10.2
Nanobiology	4.6	5.4	5.0	3.1
Communications	4.3	4.0	3.6	3.4
Other	0.4	1.3	2.4	2.2
Totals	**73.9**	**88.2**	**123.8**	**129.2**

Source: Roos, U. 2004. Germany's Nanotechnology Strategy. Berlin: British Embassy Berlin.

3C. Europe

In Europe, efforts exist at both at the national level, with a number of individual countries pursuing targeted research, and at the European Commission (EC) level, with a more broad-based program. For example the EC, under its 6th Framework Programme for Research and Technological Development, committed about 350 million euros for nanotechnology funding in 2003, which represents a third of the overall European expenditure. In a recent communication (Commission of the European Communities 2004), the European Commission endorsed a more coordinated approach to nanotechnology R&D across EU countries while acknowledging the multiple individual country programs that already exist. Germany's strategic investment can be traced to the early 1990s, when nanotechnology was identified as a field with substantial promise. As a result of sector forecasting studies commissioned by the government, over the years Germany has developed a strategy to prioritize the majority of its Federal funding toward nanoelectronics, nanoscale materials, and optical science and engineering (OECD 2002; see also Table 4). In addition to funding for R&D, German public funding is targeting infrastructure development, including research centers at various geographic locations. While the EU as a whole appears to be competing for broad nanotechnology research leadership, some of the targeted research being conducted in particular EU countries could also provide competitive advantages in particular technologies or industry sectors. NNAP recommends the close monitoring of the EU's coordinated effort and the nanotechnology initiatives of individual EU countries.

4. Areas of Opportunity

The preceding sections provide an overview of the research activity taking place around the world. To gain insight into the areas of opportunity, the NNAP members believe that it is also useful to assess the disciplines and industry sectors in which that activity is occurring.

4A. Publications

A review of the ISI database of research publications reveals that by far the largest number of articles related to nanotechnology published from 1981 to 2001 was on the subject of semiconductors (Zucker and Darby 2005). More recently, however, the number of articles related to nanotechnology and biology, medicine, chemistry, and multidisciplinary categories have grown substantially. According to Zucker and Darby, the number of publications about nanotechnology in relation to information technology also has grown.

Nano-light Bulb up to Ten Times More Efficient

Electricity accounts for about one-third of all energy consumed in the United States, and about one-fifth of all electric energy is used for lighting. But today's lighting is remarkably inefficient. Incandescent light bulbs only convert about 5% of the electricity they draw into visible light, wasting the rest as heat. Fluorescent lights, while better, are still only about 25% efficient. By comparison, a new home furnace is typically 80% efficient, and electric motors can reach 95% efficiency. Enormous opportunities exist, therefore, for saving energy through more efficient lighting.

Semiconductor-based light emitting diodes, or LEDs, can produce light much more efficiently. Early LEDs converted about 50% of electricity into light—10 times better than incandescent bulbs—but the light was a single color or wavelength and not suitable for general illumination. Developing cost-effective LEDs that produce white light—that is, light with many different wavelengths—has been a major challenge.

Researchers at the Department of Energy's Sandia National Laboratories have demonstrated a white light source with LED efficiency. The device uses a conventional LED emitting near-ultraviolet (410 nm) light to illuminate a range of nanosized semiconductor particles, or "quantum dots." The dots in turn emit light of many different colors. By mixing different sized quantum dots it is possible to create a device that produces light of any desired color, including white, as shown in the figure at the bottom left. Today, researchers are working to increase the lifetimes of these high-efficiency white-light LEDs to make them commercially viable.

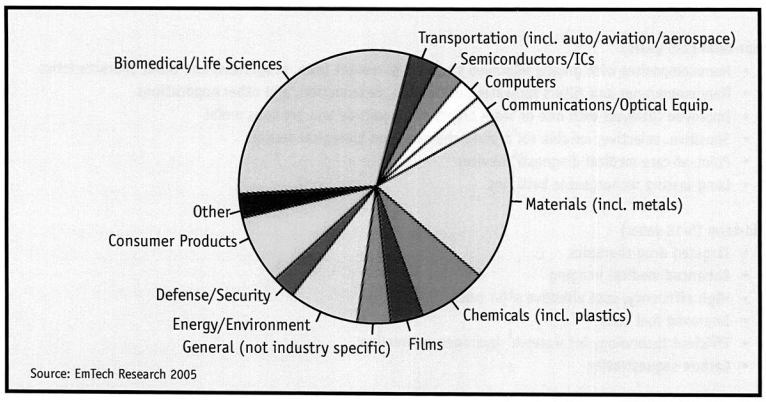
Courtesy of J. Simmons, Sandia National Laboratories

The quantum leap forward in energy efficient lighting offered by white-light LEDs can substantially impact the nation's energy consumption. If enough existing lights were replaced by LEDs to cut in half the amount of electricity used for lighting, it would reduce energy use by the amount of energy produced by 50 nuclear power plants.

4B. Patents

Based on a search of the USPTO database (Huang et al. 2004), the total number of nanotechnology-related patents increased by 217% from 1996 to 2003, contrasting with an overall increase in patents during the same period of 57%. From 1976 to 2003, about 30% of nanotechnology patents were in the chemical/catalysts/pharmaceuticals industries, 15% were in the electronics industry, and about 10% were in the materials industry. From 1997 to 2003, the chemical/catalysts/pharmaceutical sectors were observed to have the most significant growth of nanotechnology patenting activity.

Figure 5.
Target Industries for Companies Involved in R&D, Manufacture, Sale, and Use of Nanotechnology in 2004 (Total Number of Companies = 599)



Source: EmTech Research 2005

In 2003, four of the five top assignees for nanotechnology patents in 2003 were electronics companies, although the field of chemistry (molecular biology and microbiology) had the greatest number of nanotechnology patents both in 2003 and in previous years. Other technological fields that experienced rapid growth in patenting activity in 2003 were those relating to transistors and other solid-state devices, semiconductor device manufacturing, optical waveguides, and electric lamp and discharge (Huang et al. 2004).

More recently, according to an EmTech Research (2005) survey of approximately 600 companies involved in R&D, manufacture, sale, or use of nanotechnology, the top three companies based on the number of nanotechnology-related patents issued were IBM, Intel, and L'Oreal. Other companies that ranked highly were large, technology-based businesses.

4C. Private Sector Activity

It seems reasonable to expect that the private sector would invest in nanotechnology R&D in those areas in which relatively near-term commercial applications are forthcoming. According to the EmTech Research survey of nanotechnology suppliers (EmTech Research 2005), the two largest target industries are biomedical/life sciences (including drug diagnosis, analysis, delivery, and discovery; medical tools and materials; and genomics and proteomics research) and materials (including metals). If chemicals, plastics and films are also counted as materials, this is the single largest area. Despite strong activity in biotechnology and materials, the diversity of business activity—ranging from energy to consumer products—is just as notable.

The companies included in Figure 5 range in size, with the largest number being either very small (<10 employees) or large (>1000 employees). Small companies depend on funding from both public and private sources, including venture capital. A separate survey by Lux Research estimates that the distribution of approximately $1.1 billion in venture capital funding for nanotechnology invested between 1998 and 2004 has been predominantly in electronics and semiconductors (41%) and nanobiotechnology (40%). Other sectors include specialty chemicals and nanomaterials (14%) and instrumentation (5%) (Lux Research Inc. 2004).

4D. TAG-Identified Areas of Opportunity

As part of its review, the NNAP surveyed its TAG members to gain insight into what areas of research those experts thought were likely to yield high impact advances. Below is a selection of the near-, mid-, and long-term areas in which TAG members felt nanotechnology would make a significant impact.

Near-term (1-5 years)

- Nanocomposites with greatly improved strength-to-weight ratio, toughness, and other characteristics
- Nanomembranes and filters for water purification, desalination, and other applications
- Improved catalysts with one or more orders of magnitude less precious metal
- Sensitive, selective, reliable solid-state chemical and biological sensors
- Point-of-care medical diagnostic devices
- Long-lasting rechargeable batteries

Mid-term (5-10 years)

- Targeted drug therapies
- Enhanced medical imaging
- High efficiency, cost effective solar cells
- Improved fuel cells
- Efficient technology for water-to-hydrogen conversion
- Carbon sequestration

Long-term (20+ years)

- Drug delivery through cell walls
- Molecular electronics
- All-optical information processing
- Neural prosthetics for treating paralysis, blindness, and other conditions
- Conversion of energy from thermal and chemical sources in the environment

The opportunities identified by the TAG suggest the group's enthusiasm about the potential for technologies that will improve the quality of life for all by providing clean water, affordable energy, and better healthcare.

5. Other Leadership Factors

An additional concern worth mentioning when considering U.S. leadership in nanotechnology, and one that PCAST has studied extensively over the past year, is the relative decline in the number of U.S. undergraduate and graduate degrees in science, technology, engineering and math (STEM) fields. PCAST's June 2004 Report, *Sustaining the Nation's Innovation Ecosystem: Maintaining the Strength of Our Science and Engineering Capabilities* (PCAST 2004) outlines data that raise serious concerns about the pace at which other countries, particularly industrialized Asian nations, are educating their citizens in STEM-related fields.

For example, in China over 39% of undergraduate degrees in 2001 were in engineering, compared with 5% in the United States. The numbers indicate that China is producing over three times as many trained engineers as the United States. Similarly, at the post-graduate level, the number of Asian citizens awarded degrees in natural science and engineering is significantly increasing, whereas the number of comparable U.S. degrees has declined in recent years. The increase in STEM talent, especially in Asia, coupled with significantly lower wage structures, threatens to lead to greater pressure, not only on U.S.-based high-tech manufacturing, but even on leading-edge R&D. While it is unclear how this shift will impact nanotechnology specifically, it is worth taking steps to ensure that the pool of U.S. nanotechnology researchers and technical workers remains strong. In fact, nanotechnology experts from the TAG who are currently engaged in university-based nanotechnology research particularly emphasized the need for high-quality U.S. students to carry out future nanotechnology research.

6. Conclusions

By reviewing the history of nanotechnology R&D funding, it is clear that the United States has been the leader in nanotechnology up to this point. Early recognition of the potential benefits of a coordinated nanotechnology R&D initiative, along with strong financial commitment across the Federal agencies, has enabled the United States to establish this leadership position. Measures of research output in the form of patents and publications further demonstrate U.S. leadership.

Despite the optimistic numbers, the trends in all categories—investment, publications, and patents—show steady erosion in the percentage lead of the United States over time. The Federal budget for nanotechnology R&D has begun to level, whereas the cumulative investment worldwide continues to grow. The NNAP notes that programmatic investments in a given area such as nanotechnology, whether by the United States or by other nations, cannot indefinitely continue their rapid increase. The significant increases in nanotechnology funding recently made by many other nations (and regions) may reflect efforts to catch-up to the United States. Nevertheless, the NNI should monitor worldwide investment and activities and remain cognizant of the U.S. competitive position; the NNAP certainly will continue to do so. And in any event, if the United States is to maintain its leadership in nanoscale science, engineering, and technology within current tight fiscal constraints, as well as to capitalize on the resulting innovations to achieve economic and other benefits, the NNI must continue to ensure that every dollar is well spent.

CHAPTER 2: Is This Money Well Spent and the Program Well Managed?

Whereas the preceding chapter scanned the global activity for the purposes of assessing the U.S. strength in nanotechnology R&D compared to other nations, this chapter looks inward to determine if the U.S. Federal investment of over $4 billion from 2001 through 2005 has been worthwhile, and whether the management of the NNI will lead to wise investments in the future.

1. NNI Strategic Plan and Management

1A. Vision, Goals & Funding

From the outset, the NNI has been a multidisciplinary program with the following key elements:

- Basic research aimed at fundamental knowledge creation
- Applied research targeted at applications in which nanotechnology is expected to have an impact
- Infrastructure in the form of facilities, equipment and instrumentation
- Education for students of all ages, teachers, and the public, including workforce training
- Societal implications, including environmental, health, economic, ethical, legal, and other issues

In December 2004, the NNI released an updated Strategic Plan (NSTC 2004) describing the vision and goals of the Initiative, and the strategies by which those goals are to be achieved. The vision as stated in the NNI Strategic Plan is "a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry." The plan identifies four goals that must be accomplished in order to make the vision a reality:

1) Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology
2) Facilitate transfer of new technologies into products for economic growth, jobs and other public benefit
3) Develop educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology
4) Support responsible development of nanotechnology

These high-level goals directly or indirectly incorporate all of the original program elements listed above.

In addition, the Strategic Plan defines major subject areas of investment, or "Program Component Areas" (PCAs). According to the Plan, the PCAs relate to areas of investment that are critical to accomplishing the goals, cutting across the interests and needs of the participating agencies. The PCAs are:

1) Fundamental nanoscale phenomena and processes
2) Nanomaterials
3) Nanoscale devices and systems
4) Instrumentation research, metrology, and standards for nanotechnology
5) Nanomanufacturing
6) Major research facilities and instrumentation acquisition
7) Societal dimensions

Table 5.

Relationships Between Program Component Areas and the Overarching NNI Goals

Program Component Areas:	Goal 1: Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology	Goal 2: Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit	Goal 3: Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology	Goal 4: Support responsible development of nanotechnology
Fundamental Nanoscale Phenomena and Processes	critical to goal	secondary relevance	primary relevance	secondary relevance
Nanomaterials	critical to goal	secondary relevance	secondary relevance	secondary relevance
Nanoscale Devices and Systems	primary relevance	critical to goal	secondary relevance	secondary relevance
Instrumentation Research, Metrology, and Standards for Nanotechnology	secondary relevance	critical to goal	secondary relevance	secondary relevance
Nanomanufacturing	secondary relevance	critical to goal	primary relevance	primary relevance
Major Research Facilities and Instrumentation Acquisition	primary relevance	primary relevance	critical to goal	secondary relevance
Societal Dimensions	secondary relevance	secondary relevance	primary relevance	critical to goal

critical to goal
primary relevance
secondary relevance

Source: Nanoscale Science, Engineering, and Technology Subcommittee (NSET). 2004. *The National Nanotechnology Initiative: Strategic Plan.* Washington, D.C. December 2004.

The PCAs (which are defined in the Appendix) appear to provide a rational means by which the NNI investment can be categorized. Progress in each PCA is related to some degree to the achievement of the four goals as shown in Table 5. The fact that each PCA includes activities that take place within multiple agencies (as shown in Table 6) can and should result in discoveries by one agency that benefit others. Although the NNAP members believe that these PCAs can serve to focus and manage the overall investment appropriately, the Panel notes that this grouping is silent with respect to certain areas that are expected to play a significant role, in particular research at the interface of nanotechnology and biology (e.g., adaptation of biological processes for synthesis of nanostructured nonbiologic material) and research in advanced computational science for theoretical modeling and simulation of nanoscale materials and processes. Although these areas do not necessarily need to be considered as separate PCAs in their own right, the NNAP suggests that the NNI emphasize their importance within the existing PCA framework.

The NNI Strategic Plan states that "advancement may be expedited by grouping together work in a particular PCA that is taking place within multiple agencies." The NNAP agrees with this statement. To ensure that such advancement not only may but will be expedited, the NNAP recommends that the NSET Subcommittee perform a government-wide review of the work being performed within each PCA.

1B. Programmatic and Funding Balance

As previously noted, the NNI today involves over $1 billion annually in research funding that is distributed to many agencies. One of the challenges, and indeed a central reason for having a coordinated Federal research effort, is to ensure balance across the program. In the case of the NNI, balance does not refer simply to the distribution of investments among the PCAs. It also means balance between short- and long-term research, between research focused on fundamental discovery and on development of applications, and between R&D aimed primarily at advancing the technology versus research that is focused on understanding the environmental, health, and other societal implications of the new technology.

These distinctions illustrate the complexity and diversity of the NNI, qualities that offer many opportunities for investment and management. In the NNAP's view the NSET Subcommittee, in its coordination of the NNI, has been aggressive in grappling with these issues of balance. In the course of developing the Strategic Plan, the NSET Subcommittee has not only carried out internal planning activities, but also sought input from various stakeholders outside the Government through a variety of means, including open workshops.

The NNAP members believe that the NNI Strategic Plan demonstrates an appropriate approach to balancing the various aspects of the program. In particular, NNI agencies are moving responsibly to increase support for research into the environmental and health effects of nanomaterials relative to the investments in support of technological advancement. Likewise, the Strategic Plan also demonstrates an appreciation of the importance of actively transitioning research results into commercial applications.

Based on the NNI 2006 Supplement to the President's Budget (NSTC 2005a), the NNAP members believe the FY 2006 budget represents a reasonable distribution of funding among PCA categories and across participating research agencies, with the following caveats.

First, the NNAP is aware of concern among nanotechnology experts, including TAG members, about the level of participation by agencies that are expected to be substantially impacted by nanotechnology in the future, including the U.S. Department of Agriculture (USDA), the Department of Transportation (DOT), and the Department of Homeland Security (DHS). The NNAP members agree that nanotechnology research is relevant and important to the mission of these agencies, and encourage the NNI to promote awareness within the agencies of the initiative and of nanotechnology solutions to agency needs.

Second, the NNAP notes that the request for $11 million for USDA nanotechnology R&D in FY 2006 is a significant increase from $3 million to be spent in FY 2005. The NNAP members are pleased to learn that in addition to the Cooperative State Research, Education, and Extension Service of the USDA, the Forest Service has plans to develop R&D programs in nanotechnology.

Finally, whereas USDA appears to be growing its nanotechnology R&D program, DOT and DHS do not appear to be doing so. The NNAP is concerned that DHS, in particular—with its need for advanced technology solutions for sensors and materials—is investing only $1 million in FY 2005 and 2006. The NNAP encourages the NNI to reach out to agencies like DHS and DOT to further the NNI's goal of Government-wide coordination of nanotechnology R&D.

Table 6.

Relationships Between Program Component Areas and NNI Agency Missions, Interests, and Needs

● - Primary □ - Secondary

Shading indicates agencies with budgets for nanotechnology R&D in FY 2005.

	Fundamental Nanoscale Phenomena and Processes	Nanomaterials	Nanoscale Devices and Systems	Instrumentation Research, Metrology, and Standards for Nanotechnology	Nanomanufacturing	Major Research Facilities and Instrumentation Acquisition	Societal Dimensions
CPSC	□	□	●	●			●
DHS	●		●	●		□	
DOC (BIS)	□	●	●	●	□		
DOC (NIST)	□	□	□	●	●	□	□
DOC (TA)	□	□	□	□	●	□	●
DOC (USPTO)		●	●	●	●		
DOD	□	●	●	□	●	□	□
DOE	●	●	□	□	□	●	□
DOJ			●				
DOS							●
DOT	●	□	●		●		
DOTreas		●	●				
EPA	□	●	●	□	●		●
HHS (FDA)		□	●				●
HHS (NIH)	●	□	●	□	□		□
HHS (NIOSH)		□			□		●
IC	□	●	●		□		□
ITC		●	●		●		●
NASA	□	●	●		□	□	
NRC			●				
NSF	●	●	□	□	●	●	●
USDA	□	●	●		□		●

Source: Nanoscale Science, Engineering, and Technology Subcommittee (NSET). 2004. *The National Nanotechnology Initiative: Strategic Plan.* Washington, D.C. December 2004.

Quantum Dots Glow Brightly to Assist Surgeons and Aid Medical Research

In cancer surgery, after doctors remove a tumor, they also remove nearby lymph nodes and examine them for signs of malignancy. The nodes connected most directly to the tumor-affected area are called "sentinel nodes," and if they are cancer-free it is a good indication that the disease has not spread. But it can be tricky to find the sentinel node for a particular tumor.

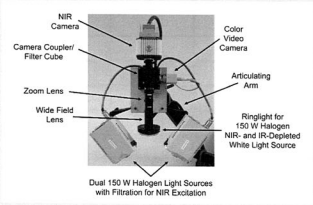
The current method for identifying sentinel lymph nodes is to inject a radioactive tracer and a visible dye near the tumor. A radiation detector locates the node and the dye provides confirmation during surgery. But pinpointing the radiation is not always accurate and the procedure requires considerable experience on the part of the doctor.

A new method has been developed by researchers at Harvard Medical School (funded by NIH) using semiconductor nanoparticles—or "quantum dots" (QDs)—which may make it much easier to find and remove sentinel lymph nodes. QDs are fluorescent, emitting light at a particular wavelength depending on their size. By tailoring the size of the QDs to approximately 15-20 nanometers, they emit light in the near infrared, a wavelength that passes harmlessly through the body, allowing the light to be detected using an infrared camera from outside the lymph node and even outside the body. The QD size must also be small enough to flow through the lymph system, but still be trapped by the nodes.

Not only do QDs eliminate the need for the use of radioactive materials, they are brighter and much longer lasting and can be sized for more efficient concentration by the lymph nodes, compared to currently available fluorescent dyes. In early studies on pigs, surgeons found the QDs make locating the sentinel lymph node much easier.

In other research at Emory University and the Georgia Institute of Technology, QDs have been attached to antibodies that bind specifically to prostate tumors in mice. These types of experiments are first steps in being able to image, identify, and ultimately treat cancers with a single agent.

The brightness and staying power of QDs also make them useful in research for imaging at the single molecule level and for tracking processes in animals or in cellular experiments over longer time periods.



QD imaging system, including visible and infrared light sources and visible and infrared cameras.

Use of the QD imaging system during animal surgery.

The photographs above are published with permission from: An Operational Near-Infrared Flourescence Imaging System Prototype for Large Animal Surgery, *Technology in Cancer Research and Treatment*, volume 2, page 558, 2003, Adenine Press, http://www.tcrt.org.

1C. Cautionary Thoughts

While the general approach to managing and funding the NNI in terms of goals and priorities seems sound, the NNAP would like to provide a few cautionary thoughts as the program moves forward:

- ***Flexibility.*** Because nanotechnology generally is in the early stages of development and deployment, it is appropriate to pursue many avenues of opportunity. At the same time, it is important to remain flexible and not to allow "institutions" to develop around specific research funding areas. Constraints on the levels of Federal funding can be expected to continue, and for the NNI to succeed priorities must be made and real opportunities pursued, even if that means scaling back or eliminating lesser priorities as the program moves forward. The overarching goal of scientific and engineering excellence is what must be remembered.

- ***Technology Transfer.*** Recognizing the increasing levels of activity by industries and by the States, the NNI should foster the greatest practical interaction among these stakeholders to stimulate innovation while protecting worker and public health and safety. While the Federal Government supports technology transfer, it must not at the same time lose sight of its primary responsibility: to advance the basic research surrounding nanotechnology.

- ***Societal Implications.*** The NNI program is appropriately aggressive in its approach to understanding and addressing the societal implications and the environmental and health effects of nanotechnology. Because research into legal, ethical, economic, and other societal effects does not require costly instrumentation, the funding required will be smaller in comparison to components where such instrumentation is a necessity. Nevertheless, such societal research is critical. The NNAP members believe that the budget that is currently directed to societal issues—approximately 8%—appears appropriate.

- ***Leveraging.*** To maximize the value of NNI efforts aimed at each of the four goals, the NSET Subcommittee should pursue interactions and partnerships with other Government and non-government organizations with related or overlapping goals and interests. Such organizations include professional societies that have educational activities, interagency groups focused on environment or manufacturing, and agencies that have not been previously engaged, such as the Departments of Education and Labor.

1D. Grand Challenges

The concept of "grand challenges" as a means of guiding and focusing the Federal R&D program on a few targeted opportunities has been widely discussed. Opinions vary among the members of the TAG. Some members argue that nanotechnology is not yet mature enough for the program to be focused on just a few applications. Others believe that such focus is precisely what is necessary to ensure the most rapid progress toward opportunities that are within 5 to 10 years' reach. In its current form, the NNI Strategic Plan does not include specific grand challenges, but rather highlights areas of application that are supported by R&D in multiple PCAs.

After considering a number of grand challenge options, the NNAP members believe that nanotechnology is at too early a stage and too diverse to be pigeonholed into a few grand challenges. The role of the Federal Government today should be to invest broadly in the best ideas for advancing knowledge in support of the NNI vision. That being said, the NNAP encourages the individual agencies, within their own nanotechnology R&D programs, to identify performance-based targets. A good example of such an approach is the Cancer Nanotechnology Plan developed by the National Cancer Institute (NCI) (http://nano.cancer.gov/alliance_cancer_nanotechnology_plan.asp). This plan identifies key areas of opportunity in which nanotechnology can address the NCI's vision of eliminating suffering and death from cancer, as well as establishes milestones for measuring progress in each area.

1E. Management

The NNI Strategic Plan outlines the management structure under which the NNI operates. The various Government and non-government organizations with a role in the NNI, and their relationships, are shown in Figure 6. As described briefly in the introduction of this report, the NSET Subcommittee of the NSTC Committee on Technology is responsible for planning, coordinating, and implementing NNI programs and activities. Under the NSET Subcommittee, there are currently four interagency working groups focused on specific issues:

- ***Nanotechnology Environmental and Health Implications (NEHI) Working Group.*** This working group brings together representatives from agencies that support nanotechnology R&D and those with responsibility for regulating the manufacture, sale, or use of materials and other products based on nanotechnology. The purposes of the working group are to facilitate the exchange of information about the environmental and health implications of nanotechnology among research and regulatory agencies, and to identify research needed to support regulatory decision-making.

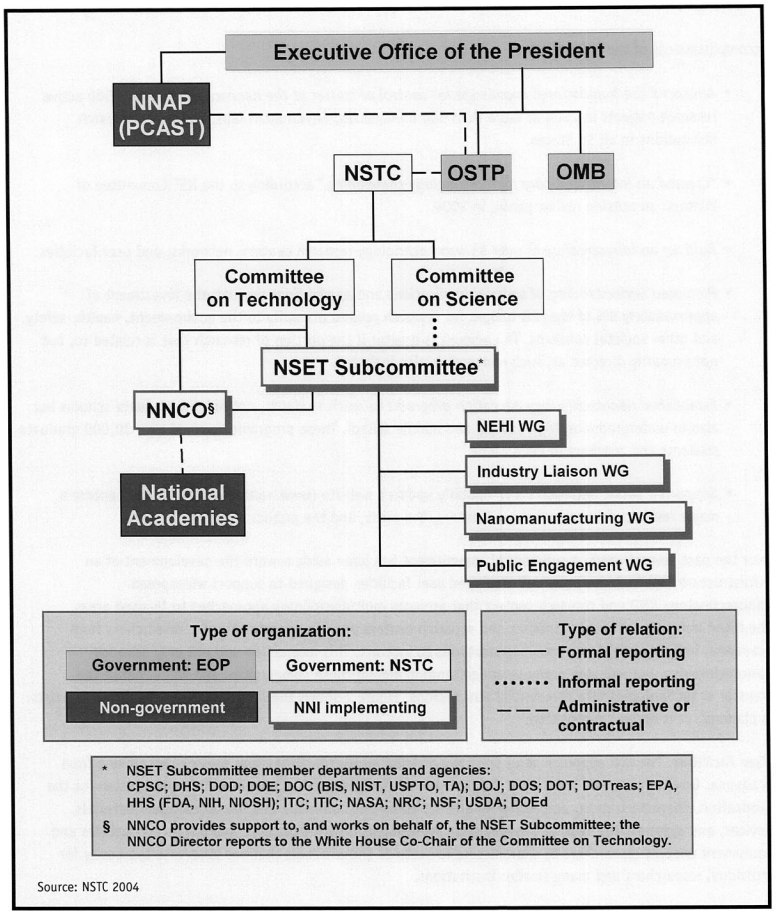
- ***Industry Liaison Working Group.*** This group works with industry representatives to establish channels through which the NNI provides the industry with information on its R&D activities, while the industry in turn offers suggestions to the NNI on how it might best support pre-competitive R&D that meets industry needs. Liaison activities already have been initiated with representatives from the semiconductor, chemical, aerospace, biotechnology, and automotive industries.

- ***Manufacturing Working Group.*** This group was established to coordinate activities related to reliable, scaled up manufacture of nanoscale materials, components, and products. Activities in this area currently are taking place primarily within NSF, the Department of Defense, and the National Institute of Standards and Technology (NIST).

- ***Nanotechnology Public Engagement Group.*** This group was recently established to develop approaches by which the NNI can communicate more effectively with the public. The NNI recognizes that most members of the general public know little about nanotechnology. As research results proceed to the marketplace, it is important that the public becomes more informed about what nanotechnology is—and what it is not.

National Nanotechnology Coordination Office. Due to the scope of the NNI and the interagency coordination activities, a National Nanotechnology Coordination Office (NNCO) was established in 2001 to provide technical and administrative support. The NNCO was made statutory by the Act. A particularly important function of the NNCO is as a conduit for information. It serves as the point of contact on Federal nanotechnology activities for both non-government parties and Government agencies that are not participating in the NNI. It also has responsibilities for public engagement and maintains the NNI website (www.nano.gov).

Figure 6.
Organizations with a Role in the NNI and Their Relationships



Source: NSTC 2004

2. NNI Accomplishments

The United States has invested heavily in nanotechnology R&D over the past several years. It is valid to ask what we have obtained from our investment and what opportunities are ahead in the short and long term.

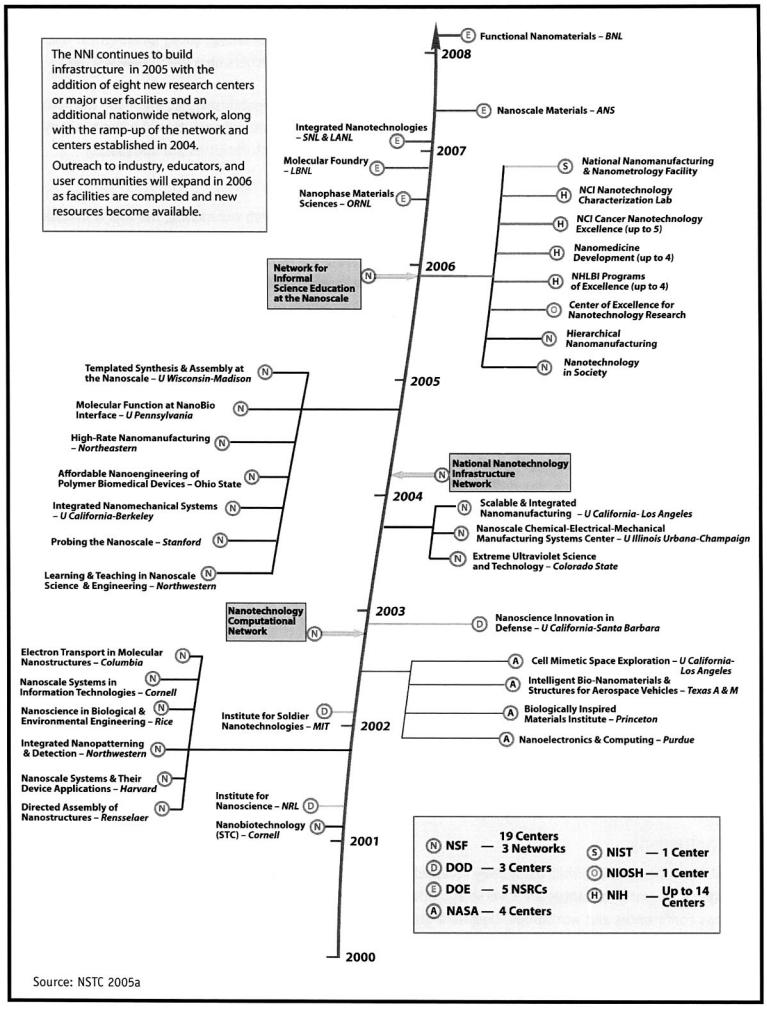
Accomplishments of the NNI include:

- *Advanced the foundational knowledge for control of matter at the nanoscale* with over 2500 active research projects in 2004 at more than 500 universities, Government labs, and other research institutions in all 50 States.
- *"Created an interdisciplinary nanotechnology community,"* according to the NSF Committee of Visitors, an outside review panel, in 2004.
- *Built up an infrastructure* of over 35 nanotechnology research centers, networks, and user facilities.
- *Promoted understanding of societal implications and applications* through the investment of approximately 8% of the NNI budget for research related primarily to the environment, health, safety, and other societal concerns. The amount is greater if the portion of research that is related to, but not primarily directed at, such concerns is also included.
- *Established nanotechnology education programs* to reach students, not only in graduate schools but also in undergraduate, high school, and middle school. These programs involved over 10,000 graduate students and teachers in 2004 alone.
- *Supported public outreach* via a regularly updated website (www.nano.gov), which has become a major resource for researchers, educators, the press, and the public.

Over the past several years, a substantial commitment has been made toward the development of an infrastructure that includes both well-equipped user facilities designed to support widespread nanotechnology R&D and research centers that promote multidisciplinary approaches to focused areas. The NNAP notes that the user facilities and research centers provide opportunities for researchers from academia, industry, and Government laboratories to interact. This interaction will not only advance nanotechnology, but will also promote understanding among these communities and will enhance the transfer of technologies into commercial applications. Figure 7 shows the infrastructure that currently exists, is planned, or is under construction.

User Facilities. The NNI supports geographically distributed user facilities that provide researchers from academia, Government, and industry with broad access to expertise and advanced instrumentation for the fabrication, characterization, and modeling and simulation of nanoscale and nanostructured materials, devices, and systems. The Federal Government's investment in such expensive and advanced facilities and equipment enables researchers to share access to state-of-the-art tools that are otherwise too costly for individual researchers and many smaller institutions.

Figure 7.
NNI User Facilities and Research Centers



Source: NSTC 2005a

NNI user facilities include the NSF-funded National Nanotechnology Infrastructure Network (NNIN) and the Network for Computational Nanotechnology (NCN). The NNIN is a network of 13 partner universities that provides fabrication and instrumentation, equipment, and expertise. The 7-member NCN supports computational research and education, as well as Internet-accessible modeling and simulation applications and algorithms. Also nearing completion are five user facilities that will be collocated with large-scale facilities at Department of Energy (DOE) laboratories. These DOE Nanoscale Science Research Centers (NSRCs) will be available to all researchers on a merit-reviewed basis.

The NNAP views Federal investment in user facilities and computational capabilities that are made available to the broader U.S. research community to be wise investments. The NNI should seek to make the availability of such facilities and capabilities widely known and should ensure that such facilities are adequately maintained and staffed.

Research Centers. In addition to user facilities that serve the broader research community, the NNI is investing in a number of centers of excellence for multidisciplinary research in focused areas. To date, nearly two dozen such centers have been established (see Figure 7) and several more are to be awarded in 2005. Typically, each center, although led by a single university, involves researchers from multiple universities, with partners from industry, and sometimes from Federal laboratories as well. These centers provide valuable opportunities for researchers from various disciplines to work cooperatively on a focused research topic. In addition, by integrating researchers from academia, industry, and Government, the centers create a "hothouse" environment for ideas and innovation, as well as enhance the transition of basic research into commercial applications.

Members of the TAG differ on the optimum number of centers, and even on whether the research results at such centers are superior to the results that might otherwise be obtained by small research teams. Whereas the traditional model of investment in individual investigators is perhaps ideal for the support of curiosity (or knowledge-driven) research, the multidisciplinary, multi-investigator research center approach can lead to more rapid and systematic advancement.

Over the past decade or more, NSF has gradually increased the fraction of its agency-wide funding that is spent on centers vs. individual investigators or small research groups. Today, the agency invests roughly 20% in centers across the agency and within its NNI portfolio. The NNAP members believe that nanotechnology research is particularly multidisciplinary in nature and therefore may benefit more from investment in large centers than would many other technologies.

Although NSF, with its broad mission to advance knowledge, supports multidisciplinary centers, there may be an even more compelling case for mission-oriented NNI agencies such as the Department of Defense and the National Aeronautics and Space Administration (NASA) to consider a greater use of application-oriented research centers. Nevertheless, the establishment of centers across NNI should be carefully managed to avoid unnecessary duplication, and a balance should be maintained between research to be done in centers and that to be done by smaller research teams.

3. Conclusions

The NNAP members believe that the money invested by the Federal Government in nanotechnology has been wisely spent. Research advances are diverse and abundant, as disclosed in patents and publications and at numerous conferences and workshops. Despite a growing number of products that incorporate nanotechnology, in general, our fundamental understanding of nanoscale processes and behaviors is at a very early stage, and many applications will not be developed until well into the future. It is critical, therefore, that the Federal Government sustain its investment to ensure that the United States continues to be a leader in this emerging technology and reaps the resulting benefits.

CHAPTER 3: Are We Addressing Societal Concerns and Potential Risks?

The development and application of any new technology has societal effects. For example, advances in assistive technologies have enabled people with disabilities to participate in and contribute to their communities and workplaces in ways not previously possible. New technologies, however, can displace older ones, leading to a parallel shift in job opportunities; because new jobs potentially require different skills, such changes pose challenges for workforce training and the educational system. Unintended hazardous effects to the environment and public health also impact society. Finally, advances in technology often raise ethical questions, such as effects on personal privacy, medical ethics, and access to benefits.

The NNI has recognized the need to address each of these areas. Its efforts in this area are focused and coordinated under the Program Component Area on Societal Dimensions. In the FY 2006 budget, $82 million (8% of the total NNI budget) is requested within this PCA.

Details of the NNAP's evaluation of NNI activities to assess and address societal implications and risks are provided below.

1. Environmental, Health, and Safety

The possibility of unintended and undesirable consequences depends on two factors—hazard and exposure. Although researchers must be cognizant of potential hazards when working with new materials having unknown properties, these activities pose little risk to the public or the environment. As new technologies begin to find application in manufacturing processes and in commercial products, however, the potential risks beyond the lab environment must be understood. The NNAP notes that many technologies and products have associated risks that are successfully managed in order to gain their benefits—for example, gasoline, electricity, and medical X-rays.

The state of knowledge with respect to the actual risks of nanotechnology is incomplete. The NNI is funding research within several agencies to develop a broad understanding of the environmental and health effects of nanotechnology, in particular those nanomaterials that show the most promise for commercial use. The NNAP draws special attention to the ongoing research by the National Toxicology Program (an interagency program within the Department of Health and Human Services) to determine the toxicity of specific nanomaterials, and by the National Institute for Occupational Safety and Health to ensure worker safety. The NNAP members believe that the greatest likelihood of exposure to nanomaterials is during manufacture, and therefore agree with the prioritization of research on potential hazards from workplace exposure.

Of the total amount to be spent on researching the societal dimensions and impact of nanotechnology, the NNI plans to invest about half of the NNI budget allocated to this PCA for FY 2006, or 4% of the total budget, for R&D that is aimed primarily at understanding and addressing the potential risks posed by nanotechnology to health and the environment. This amount does not include substantial research that has a different primary focus but that nonetheless extends our knowledge of health and environmental effects of nanomaterials. Many projects funded by the National Institutes of Health fall into this category. For example, research on the use of nanoparticles for medical imaging would likely include a basic biocompatibility evaluation. In order to estimate the level of this secondary contribution, the NNAP has engaged the Science and Technology Policy Institute to conduct a survey of NIH-funded nanotechnology research projects.

The Federal Government has a role not only in funding research on environmental and health effects, but in setting appropriate standards, guidelines, and regulations to protect the public and the environment. The NNAP members are pleased to note the formal establishment of the Nanotechnology Environmental and Health Implications Working Group under the NSET Subcommittee. The working group has enabled exchange of information among research and regulatory agencies and has brought together a group that can both identify the research needed in support of regulatory decision-making and implement those priorities into the R&D program.

2. Education and Workforce Preparation

The widespread application of nanotechnology in coming decades means that the United States will need trained workers in many fields, including future researchers in every technical discipline, skilled technicians for jobs in various industries, and teachers at all levels. The pipeline that produces new researchers, technicians, and science teachers is fed by a stream of primary and secondary students. The exciting prospects offered by nanotechnology are attracting students of all ages to learn more.

The need to provide and support a range of education and training activities is an integral part of the NNI. The principal mechanism by which the NNI provides education is through research grants to university researchers. These grants support graduate and postdoctoral training at the cutting edge of nanoscale science, engineering, and technology R&D.

The National Science Foundation is the lead NNI agency for education-related programs beyond graduate training through research grants. The agency plans to invest about $28 million in FY 2006 for nanotechnology educational programs, including curriculum development in universities, the integration of research and education, distance learning, and courses and tutorials by professional societies. In addition, NSF-funded university-based centers are required to provide educational and outreach services to a broad audience, for example to teachers, the broader university community, or the public.

NSF is funding two activities focused specifically on nanotechnology education. First, the agency is funding the Nanotechnology Center for Learning and Teaching at Northwestern University to develop scientist-educators at the middle school, high school, and undergraduate levels. The center also will serve as a clearinghouse for curricular materials, instructional methods, and activities in nanotechnology education. More than 12,000 students and teachers are expected to be involved in NSF's nanotechnology education programs in FY 2006.

Second, in an effort to improve informal education—that is, learning outside of traditional classroom settings—NSF plans to award a grant in 2005 for the establishment of a network that links science museums and other informal science education organizations with nanoscale science and engineering research organizations. The goal of this network is to foster public awareness and understanding of, and engagement with, nanoscale science, engineering, and technology.

Taken together, these efforts are expected to help grow the workforce that will be needed to fill the anticipated demand. However, the NNAP members strongly believe that more needs to be done to bolster the number of STEM graduates and teachers and encourage the NNI to continue to build upon the existing programs.

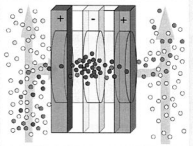
Nanoengineered Membranes Generate Clean Water, Save Energy, and Recycle Resources

Access to clean water is a public health issue of global proportions. In the developing world, 80% of all disease is water-related, and providing access to clean water is perhaps the single most important step to improving health. In some areas of developed countries like the Western United States, agricultural practices and other activities contaminate scarce water supplies. In California alone 4,000 water wells have been shut down due to nitrate contamination from farms, feedlots, and septic tanks. Reverse osmosis and other existing methods for producing clean water are too inefficient and costly for widespread use.

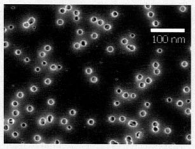
With support from the Department of Energy (DOE) through Laboratory Directed Research and Development funding, researchers at Lawrence Livermore National Laboratory (LLNL) are nanoengineering membrane systems using sophisticated computer modeling and advanced manufacturing technology. At the heart of the devices are electrically conductive membranes with tightly controlled pore sizes of just a few nanometers (see figures below).

By requiring less energy and by removing only targeted pollutants while leaving behind benign or beneficial compounds, nanoporous membrane systems reduce treatment costs by at least half compared to conventional technologies. LLNL is focusing on systems that remove nitrate, perchlorate, arsenic, and selenium, but the technology can be tailored to extract many other contaminants as well. Application of these new membrane technologies can add millions of acre-feet of low-cost water to the Western United States, where water shortages are becoming acute.

The same technology can be used to recycle resources and minimize waste in industrial processes. DOE estimates that replacing energy-inefficient processes used in industry today, including evaporation and distillation, with selective nanomembrane technologies could save one "quad" or 10^{15} BTUs, the equivalent of 1% of total U.S. energy use.



Schematic showing system with membranes of engineered nanopores (left) in electrically conductive materials. System selectively removes target species, allowing low-cost treatment of water containing toxic substances such as arsenic, or pathogens such as viruses.



Field emission scanning electron micrograph of a "smart" membrane with pores drilled to 10 nanometers in diameter—the size needed for nitrate ions to pass through. Nitrate is a major drinking water contaminant in agricultural areas.

Graphics courtesy of William Bourcier, LLNL

3. Ethical, Legal, and Other Societal Implications

Nanotechnology, like biotechnology, has the potential to require individuals, corporations, and governments to make decisions that have ethical, legal, and other societal implications. To address such issues, the NNI must actively engage scholars who represent disciplines that might not have been previously engaged in nanotechnology-related research. Moreover, these efforts should be integrated with conventional scientific and engineering research programs so that the people who develop nanotechnology are more fully aware of the societal implications of their work.

4. Public Engagement

In the United States, the public is generally very supportive of the Federal Government's investment in scientific research. In 2001, 81% of NSF survey respondents agreed with the statement "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government" (NSB 2002). To sustain this support, the scientific community and the Federal agencies that fund scientific research must communicate more directly with the public, not through surrogates such as the entertainment industry.

Through the NNI website and through outreach activities at the NSF-funded centers and DOE user facilities, the NNI has established channels to communicate with members of various stakeholder groups, including the broader public. In addition, the NSET Subcommittee recently formed a subgroup focused on public engagement activities. The NNAP will follow the group's progress. For its own part the NNAP has held open meetings focusing on nanotechnology issues, which have provided the public with several opportunities to provide input.

5. Conclusions

The members of the NNAP compliment the NNI for recognizing, early on, that nanotechnology can have potentially broad societal implications—both positive and negative—and for taking steps to understand and, where necessary, to address these implications. The NNAP members believe that the level of funding for research related to societal aspects of nanotechnology is adequate at this time but that the NNI must ensure that the results are disseminated appropriately. In particular, information on environmental or health effects should be shared, especially with those who have regulatory responsibilities.

In addition, the NNAP cannot emphasize too strongly the importance of building the education infrastructure that will be needed to support the development and application of nanotechnology. Although not generally included as a "societal concern" when policymakers and others discuss nanotechnology, education should be an element of the discussion. The NNI has many excellent programs in this area, which should be held up as a model for other parts of the Federal R&D enterprise.

CHAPTER 4: How Can We Do Better?

Since its inception, the NNI has done a very good job of organizing the pertinent Federal Government agencies around the nanotechnology topic, establishing a robust national research infrastructure, and—through the NSET Subcommittee and the NNCO—coordinating and tracking programmatic activity. With 22 different participating agencies, each with its own distinct mission, these accomplishments deserve high praise.

The NNI's success has contributed to increased levels of public attention and to more acute international competition, and thus to new challenges. The NNI initially provided the means to spur and organize agency participation. Although it continues to serve this purpose by steadily engaging additional agencies, in the future NNI will increasingly be called upon to show progress and demonstrate real added value as well.

The NNAP members are impressed with the NNI program in general, and offer the following recommendations to further strengthen it in light of expected fiscal constraints. In addition to program management and funding issues, a number of other issues have emerged that warrant special consideration; these are outlined below along with the Panel's recommendations.

1. Program Investment Areas and Funding Levels

Upon reviewing the NNI Strategic Plan issued in December 2004, NNAP members believe that, overall, the Plan provides an appropriate framework under which to implement a broadly based Federal R&D program. The Program Component Areas are appropriate for the program at this time; however, the NNAP recommends that PCAs be assessed periodically to ensure that they adequately cover and describe the entire scope of the NNI R&D portfolio. To accelerate progress in the various PCAs, the NNAP further recommends that the NNI: (1) review activities Government-wide, and (2) identify one or more research targets within each PCA.

The Administration has made nanotechnology an R&D priority. The NNAP members believe that it is critical that the United States maintain a leadership position in nanotechnology and therefore recommend continued robust funding for the NNI.

Beyond this fundamental endorsement, the NNAP also recommends several additional items for NNI consideration, as indicated in the following sections.

2. Technology Transfer

The Federal Government is developing strategies to assist U.S. companies in accelerating the commercial development of nanotechnology, particularly in areas where commercial development complements U.S. Government requirements. Today, most nanotechnology products on the market are produced by large businesses and are evolutionary in nature--although with real performance improvements (e.g., powders for composites and coatings and nanostructured semiconductor devices). Although efforts are being made to accelerate the transition of nanotechnology into practical use, nanotechnology is still primarily "nanoscience"—that is, the technological developments are at a very early stage. The time to commercialization for many of the resulting technologies is estimated to be a decade or more. Startup companies are forming, but in most cases, their products are still under development.

Nanotechnology start-ups and other industry players commonly appeal for funding to transition research into the prototyping and product development stages. There is disagreement about the point in the development cycle at which the Government should hand off to the private sector. Although funding for nanotechnology product development may be appropriate to meet specific agency mission requirements (for instance biological sensors for the Departments of Homeland Security and Defense), there is an ongoing policy debate regarding whether the U.S. Government should fund commercial product development that is not directly tied to Government requirements. Many would argue that if a yet-to-be developed product had true commercial appeal, commercial investors would step up to fund this transition. Others argue that, particularly for novel technologies like nanotechnology, the Federal Government has an interest in helping to accelerate commercial development in order to ensure U.S. economic leadership in this area.

PCAST has studied the issue of technology transfer extensively over the past several years, and takes the position that while the Federal Government can take steps to help promote technology transfer, the primary responsibility for funding product manufacturing should be left to the private sector with appropriate assistance from State and local governments. Indeed, private networks to help manufacture new nanotechnology products are forming (see, for example, the MEMS and Nanotechnology Exchange at: http://www.mems-exchange.org). Furthermore, States are investing heavily in nanotechnology as part of their respective economic development strategies.

2A. Federal Government Role

It is the opinion of the NNAP that the first and most important responsibility of the Federal Government with respect to nanotechnology is to fund the basic research that will form the intellectual foundation for eventual commercial development and exploitation. In other words, the United States needs great science and great engineering. The Federal Government has a rich history of funding basic research, which has resulted in discoveries that underlie many entrepreneurial and economic success stories. It is critical that the United States continue this tradition in the area of nanotechnology. While the intense international competitive pressure makes it tempting to "rush to market," the leadership position of the United States in nanotechnology depends heavily on the intellectual property amassed through a commitment to building and supporting a base of fundamental knowledge.

The NNAP members strongly believe that, at this stage in the development of nanotechnology research, the best way to ensure U.S. economic leadership in nanotechnology is for the Federal Government to continue focusing on and funding basic nanotechnology research, including support for advanced instrumentation and infrastructure. This is not to say that the Federal Government should ignore opportunities for research that is to be transitioned for commercial gain. Existing programs can provide assistance in this area. The Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs are available at U.S. Government research agencies to fund the critical early stages of technology development, including nanotechnology. According to the NNI FY 2006 Supplement to the President's Budget (NSTC 2005a), several agencies within NNI specify nanotechnology as a focus area in their SBIR solicitations. These grants are often highly leveraged by the recipients, serving to catalyze additional State and private funding. Government agencies pursuing nanotechnology research should encourage promising nanotechnology technology development projects through established programs, such as SBIR and STTR.

In the past the Federal Government has played a vital role in the development of new technologies by being an "early adopter" customer. That is, the Government's willingness to pay a premium price up front for leading-edge technology that offers improved performance, such as advanced semiconductor electronics in the 1960s, eventually led to the development of affordable, reliable consumer products that formed the basis of an important consumer industry. The Federal Government, through its mission agencies, should look for opportunities to develop and use, in support of those missions, products that arise from Federal nanotechnology research.

2B. Federal—Industry Interaction

In addition to utilizing programs such as SBIR and STTR, the NNAP members believe the NNI can and should interact with industry to ensure communication of private sector nanotechnology research needs, as well as to provide industry insight into the latest Federal nanotechnology research breakthroughs. The NNAP endorses the approach the NNI has taken in establishing liaison activities with various industry sectors and encourages expanding such activities to other sectors where appropriate.

2C. Federal—State Interaction

Although the Federal Government's efforts have been focused appropriately on nanotechnology research, it is noteworthy that many States have recognized the economic benefits that might be reaped by investing in coordinated regional initiatives (e.g., business incubators, research centers, or research consortia) to capitalize on the results of the Federally funded nanotechnology research.

The NNAP's examinations of the nature of successful innovation have demonstrated that State governments and local and regional organizations can and do play a vital role. State and local governments can play a crucial role in helping to promote commercialization of Federal nanotechnology research, and the NNI should aggressively extend its outreach and planning activities to the States.

The NNAP members applaud the NSET Subcommittee and the Department of Commerce for sponsoring a workshop on regional, State, and local initiatives in nanotechnology in the Fall of 2003. The NNAP recommends continued interaction with States through additional conferences, workshops, and other communication to assist their progress, to ensure they are fully aware of available NNI resources such as user facilities, and to seek additional mechanisms by which technology transfer may take place.

3. Program Management

The NNAP offers a number of program management observations and recommendations:

3A. NSET/NNCO Structure and Functions

The NNAP endorses the current NNI program management structure. The NNAP finds that the NSET Subcommittee is engaged and is committed to fulfilling its obligations under the Act. The NNAP also finds that the NNCO provides appropriate support to the NSET Subcommittee in the administrative functioning of the NNI program. Communication among those responsible for coordination of the NNI occurs via regular meetings of the NSET Subcommittee. The active involvement of OSTP and OMB further helps to ensure that NNI addresses Government-wide priorities. Formation of subgroups to address specific topics (i.e., environmental and health issues, industry liaison, nanomanufacturing, and public engagement) has facilitated important activities in those areas. This type of focused interagency exchange is helpful in addressing some of the more pertinent issues relating to nanotechnology R&D, and should be continued.

As nanotechnology becomes integrated in more Federal agencies, it will be even more important for the NSET Subcommittee to retain the flexibility needed to add, delete, or alter the subjects or composition of these interagency working groups to ensure that the NNI continues to focus on the most salient issues and that the growth at the Subcommittee level does not impede the accomplishment of interagency coordination. The NSET Subcommittee has been successful in addressing specific areas through the formation of topical subgroups. Given the growing level of activities taking place outside the United States, the Subcommittee should consider establishing a group to track international activities and to identify opportunities for collaboration, for example in the area of environmental and health effects.

3B. Infrastructure and Knowledge Management

The NNI has made great strides in its effort to establish a geographically distributed infrastructure of instrumentation, expertise, and facilities. In addition, the investment in a diverse portfolio of research has resulted in greater knowledge of nanoscale processes and phenomena and of ways in which that knowledge might be put to practical use. Much of that knowledge is represented in publications, patent applications, and other documents. To maximize the likelihood that good ideas for nanotechnology R&D are acted upon, the NNI should consider means by which it can collect and share information about instrumentation and facilities that are available to the broad research community. More challenging, but also valuable, would be for the NNI to develop a system for tracking and making available information about published results and technologies that are available for commercialization.

3C. Streamlined NNI Grant Reporting

At the researcher level, the NNAP has detected an issue that the NSET Subcommittee should address. Many of the key principal investigators (PIs), whether part of a center or not, have grants from many agencies in support of their work. Each agency requires, in many cases, individual reports. The NSET Subcommittee should look for ways to streamline the reporting requirements on individual PIs so that maximum reporting efficiency is achieved.

3D. Coordination with Other Interagency Groups

In addition to addressing specific issues through formation of subgroups, the NSET Subcommittee should proactively engage other interagency groups that have overlapping interests and activities. An example of an interagency group that has overlap is the NSTC Interagency Working Group on Manufacturing Research and Development, which has identified nanomanufacturing as an area for focused manufacturing R&D. Activities by such groups clearly need to be coordinated with the NNI. Similarly, the NSET Subcommittee's NEHI Working Group should be engaged at the appropriate level with the NSTC Subcommittee on Health and the Environment.

3E. Involvement by Other Agencies

The NNAP recommends that the NNI take steps to involve other agencies in NNI coordination activities where appropriate. In particular, as the NNI activities around education and workforce development continue to grow, it will be critical to engage further the Departments of Education and Labor. The Department of Education has programs specifically aimed at improving STEM education that could benefit from NNI-funded research on education and development of educational materials. Similarly, the Department of Labor has workforce preparedness programs that would benefit from better understanding of nanotechnology-enabled industries and their needs.

4. Societal Implications

An important aspect of exploring any new technology is to consider the impacts, both positive and negative, on society. Since its inception, the NNI has been considering the societal implications associated with nanotechnology, including implications for the environment, health, the workforce, the law, and ethics. Support for the continued advancement of nanotechnology research, and eventual integration of nanotechnology into consumer products and useful applications, will depend heavily on the public's acceptance of nanotechnology. Governments around the world must take a proactive stance to ensure that environmental, health, and safety concerns are addressed as nanotechnology research and development moves forward in order to assure the public that nanotechnology products will be safe.

The NNI's role in addressing societal concerns is primarily one of coordination and communication. The program, through the NSET Subcommittee, should coordinate with the agencies that have the responsibility and authority for protecting the environment and the public. The NNAP members believe that, at this time, the emphasis should be placed especially on ensuring workplace safety where nanomaterials are manufactured or used, because such places are where the greatest likelihood of exposure exists. Moreover, because such concerns reach beyond borders, the NNI should also coordinate with agencies and organizations that are responsible for representing the United States in international forums, including the State Department, OSTP, and others.

In addition to its coordinating role, the NNI, through the NNCO, should vigorously communicate with various stakeholders and the public about the Government's efforts to address societal concerns. Without such communication, public trust may dissipate and concerns based on information from other sources, including the entertainment industry, may become dominant.

Finally, there is an expanding need for activities that are focused on ethical, legal, and other societal implications beyond just the environmental and health effects. The NNI should participate in appropriate dialogues with stakeholders beyond the research and technical communities.

5. Education/Workforce Preparation

For nanotechnology to continue developing into more than just a "research project," the education and workforce preparation infrastructure must be improved. Through grants to universities, undergraduate and graduate students receive the education and training that will allow them to become the next generation of researchers. However, to ensure that adequate numbers of skilled technicians and STEM educators are available for jobs in both nanotechnology-related industry and education, the NNAP reiterates its suggestion that the NNI interact more strongly with the Departments of Education and Labor. High-quality STEM education at all levels, beginning with the primary grades, is critical to remaining competitive in nanotechnology research and in related industries. Regarding continuing education and professional development, the NNI should expand its interaction with professional societies that have continuing education as a mission in order to promote the development of training opportunities for mid-career professionals.

6. NNAP Report Schedule

Based on the rapid pace of research and the high degree of uncertainty regarding commercial outcomes, regulations, and societal impacts, the NNAP members believe the schedule for updating the NNI Strategic Plan every three years is appropriate. The NNAP had the opportunity to participate in the NSET Subcommittee planning process and looks forward to a continued close relationship. In order to provide timely input to the NSET Subcommittee, the NNAP recommends that the schedule for its review be adjusted to not less frequently than every three years to parallel the schedule for updating the NNI Strategic Plan, with an offset of one year to allow the Plan to incorporate NNAP recommendations. That is, the next NNAP review should be in two years (one year before the next scheduled update of the NNI Strategic Plan), and thereafter, reviews should be made every three years.

CHAPTER 5: Concluding Remarks and the NNAP's Future Areas of Focus

In summary, the NNAP supports the NNI's high-level vision and goals, and the investment strategy by which those are to be achieved. The Panel members feels that the program can be strengthened by extending its interaction with industry, State and regional economic developers, and internationally, where appropriate.

This report of the NNAP has focused on the U.S. competitive position. To date, the NNI has helped to bring the United States to a global leadership position in nanotechnology, but that status is being aggressively challenged by other nations, and the United States cannot rest on its laurels. In support of continued monitoring in this area, the NNAP has chartered a study by STPI to develop the means by which investments by various nations may be normalized to allow for more accurate and thus informative "apples to apples" comparisons.

The NNAP will, as part of the Act's mandate, report periodically with a basic program assessment. Beyond this, the NNAP also intends to explore other areas of concern in greater depth. As this report is being finalized, and pending other developments that must be addressed, attention will next be focused among the following issues:

- Commercialization and technology transfer;
- Education and training, including whether the U.S. will have an adequate workforce to take advantage of the discoveries and innovations occurring in nanotechnology;
- Environmental health and safety, including Federal programs in environmental, health, and safety assessment and interagency and international coordination;
- The linkage between the Federal expenditures on Nanotechnology R&D and the Nation's national security and economic growth objectives; and
- Continued monitoring and updating of the United States' competitive posture.

APPENDIX - NNI Program Component Areas

The following text is excerpted from the NNI supplement to the President's FY 2006 Budget.

Program Component Areas (PCAs) are defined by the Act as major subject areas under which related NNI projects and activities are grouped. Whereas the NNI goals embody the vision of the initiative and provide structure for its strategy and plans, the PCAs relate to areas of investment that are critical to accomplishing those goals. These areas cut across the interests and needs of the participating agencies and indicate where advancement may be expedited through coordination of work by multiple agencies. The PCAs are intended to provide a means by which the NSET Subcommittee, as the interagency coordinating body; the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB); Congress; and others may be informed of and direct the relative investment in these key areas. The PCAs also provide a structure by which the agencies funding R&D can better direct and coordinate their activities. Agency plans for each PCA will be included in the annual NNI supplement to the President's budget, commencing with this report for 2006. The seven PCAs are defined as follows:

1. Fundamental Nanoscale Phenomena and Processes

Discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Elucidation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.

2. Nanomaterials

Research aimed at discovery of novel nanoscale and nanostructured materials and at a comprehensive understanding of the properties of nanomaterials (ranging across length scales, and including interface interactions). R&D leading to the ability to design and synthesize, in a controlled manner, nanostructured materials with targeted properties.

3. Nanoscale Devices and Systems

R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. Includes the incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nanoscale, but the systems and devices themselves are not restricted to that size.

4. Instrumentation Research, Metrology, and Standards for Nanotechnology

R&D pertaining to the tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. Also includes R&D and other activities related to development of standards, including standards for nomenclature, materials, characterization and testing, and manufacture.

5. Nanomanufacturing

R&D aimed at enabling scaled-up, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems. Includes R&D and integration of ultra-miniaturized top-down processes and increasingly complex bottom-up or self-assembly processes.

6. Major Research Facilities and Instrumentation Acquisition

Establishment of user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the Nation's scientific infrastructure for the conduct of nanoscale science, engineering, and technology research and development. Includes ongoing operation of user facilities and networks.

7. Societal Dimensions

Various research and other activities that address the broad implications of nanotechnology to society, including benefits and risks, such as:

- Research directed at environmental, health, and safety implications of nanotechnology development and risk assessment of such impacts**
- Education
- Research on the ethical, legal, and societal implications of nanotechnology.

**Environmental, health, and safety (EHS) research and development (R&D) on the EHS implications of nanotechnology includes efforts whose primary purpose is to understand and address potential risks to health and to the environment posed by this technology. Potential risks encompass those resulting from human, animal, or environmental exposure to nanoproducts – here defined as engineered nanoscale materials, nanostructured materials, or nanotechnology-based devices, and their byproducts.

GLOSSARY

ATIP	Asian Technology Information Program
BIS	Bureau of Industry and Security
CPSC	Consumer Product Safety Commission
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DOS	Department of State
DOT	Department of Transportation
DOTreas	Department of Treasury
EC	European Commission
EHS	Environmental health and safety
EPA	Environmental Protection Agency
EU	European Union
FDA	Food and Drug Administration
FFRDC	Federally Funded Research and Development Center
FY	Fiscal Year
ISI	Institute for Scientific Information
ITC	International Trade Commission
ITIC	Intelligence Technology Innovation Center
MEMS	Microelectromechanical Systems
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute
NCN	Network for Computational Nanotechnology
NEHI	Nanotechnology Environment and Health Implications (NSET working group)

NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NNAP	National Nanotechnology Advisory Panel
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NRC	National Research Council (National Academies)
NRC	Nuclear Regulatory Commission
NSET	Nanoscale Science, Engineering, and Technology Subcommittee (NSTC)
NSF	National Science Foundation
NSRC	Nanoscale Science Research Center
NSTC	National Science and Technology Council
ONAMI	Oregon Nanoscience and Microtechnologies Institute
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PCA	Program Component Area
PCAST	President's Council of Advisors on Science and Technology
PI	Principal Investigator
SBIR	Small Business Innovation Research Program
STEM	Science, technology, engineering, and math
STPI	Science and Technology Policy Institute
STTR	Small Business Technology Transfer Program
TA	Technology Administration
TAG	Technical Advisory Group
USPTO	United States Patent and Trademark Office
USDA	United States Department of Agriculture

REFERENCES

Asian Technology Information Program (ATIP). 2003. *Nanotechnology in Asia 2003.*

Asian Technology Information Program (ATIP). 2004. *Japanese 2004 S&T Budget.*

Bush, George W. 2001. *Executive Order: President's Council of Advisors on Science and Technology,* October 1, 2001, http://www.whitehouse.gov/news/releases/2001/10/20011001-1.html.

Bush, George W. 2004. *Executive Order: Amending the President's Council of Advisors on Science and Technology to Serve as the National Nanotechnology Advisory Panel,* July 23, 2004, http://www.whitehouse.gov/news/releases/2004/07/print/20040723-12.html.

Commission of the European Communities. 2004. *Communication from the Commission: Towards a European strategy for nanotechnology.* Brussels: the Commission.

Committee on Science, Engineering, and Public Policy. 2000. *Experiments in International Benchmarking of US Research Fields.* Washington, D.C.: National Academy Press.

EmTech Research. 2005. *2005 Nanotechnology Industry Category Overview.* Ann Arbor, MI: EmTech Research (a division of Small Times Media).

Huang, Z., H. Chen, Z.-K. Chen, and M. Roco. 2004. *International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis based on USPTO Patent Database. Journal of Nanoparticle Research,* 6:325-354.

Larson, D. R., Zipfel W. R., Williams, R. M., Clark, S. W., Bruchez, M. P., Wise, F. W., Webb, W. W. 2003 Water-Soluble Quantum Dots for Multiphoton Fluorescence Imaging in Vivo. *Science,* 300:1434-1436.

Lux Research, Inc. 2004. *The Nanotech Report 2004™: Investment Overview and Market Research for Nanotechnology (Third Edition).* New York: Lux Research, Inc.

Lux Research, Inc. 2005. *Statement of Findings: Benchmarking U.S. States in Nanotech.* New York: Lux Research, Inc.

National Research Council (NRC). 2002. *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative.* Washington, D.C., 2002: National Academy Press, http://www.nap.edu/books/0309084547/html.

National Science Board. 2002. *Science and Engineering Indicators – 2002* (NSB-02-1). Arlington, VA: National Science Foundation, 2002, http://www.nsf.gov/sbe/srs/seind02/c7/c7h.htm.

National Science and Technology Council (NSTC). Nanoscale Science, Engineering and Technology Subcommittee (NSET). 2004. *The National Nanotechnology Initiative: Strategic Plan.* Washington, D.C.: the Council, http://www.nano.gov/NNI_Strategic_Plan_2004.pdf.

National Science and Technology Council (NSTC). Nanoscale Science, Engineering and Technology Subcommittee (NSET). 2005a. *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's FY 2006 Budget.* Washington, D.C.: the Council, http://www.nano.gov/NNI_06Budget.pdf.

National Science and Technology Council (NSTC). 2005b. *Regional, State, and Local Initiatives in Nanotechnology: Report of the National Nanotechnology Initiative Workshop, September 30 - October 1, 2003.* Washington, D.C.: the Council, http://www.nano.gov/041805Initiatives.pdf

Organisation for Economic Co-operation and Development (OECD). Working Party on Innovation and Technology Policy. 2002. *Nanotechnology R&D Programmes in the United States, Japan and the European Union: A Preliminary Review.* Paris: the Organisation.

President's Council of Advisors on Science and Technology (PCAST). 2004. *Sustaining the Nation's Innovation Ecosystem: Report on Maintaining the Strength of Our Science & Engineering Capabilities.* Washington, D.C.: The Council, http://www.ostp.gov/pcast/FINALPCASTSECAPABILITIESPACKAGE.pdf.

U.S. Congress. Public Law 108-153. 2003. 21st *Century Nanotechnology Research and Development Act.* 15 USC 7501. 108 Cong., 3 December 2003.

Roos, U. 2004. *Germany's Nanotechnology Strategy.* Berlin: British Embassy Berlin.

Small Times. 2004. *Nanotechnology: Industry Category Overview,* prepared for the National Nanotechnology Coordination Office.

Zucker, L. G. and M. R. Darby. 2005. *Socio-economic Impact of Nanoscale Science: Initial Results and Nanobank. National Bureau of Economic Research,* NBER Working Paper No. 11181.

President's Council of Advisors on Science and Technology • May 2005
www.ostp.gov